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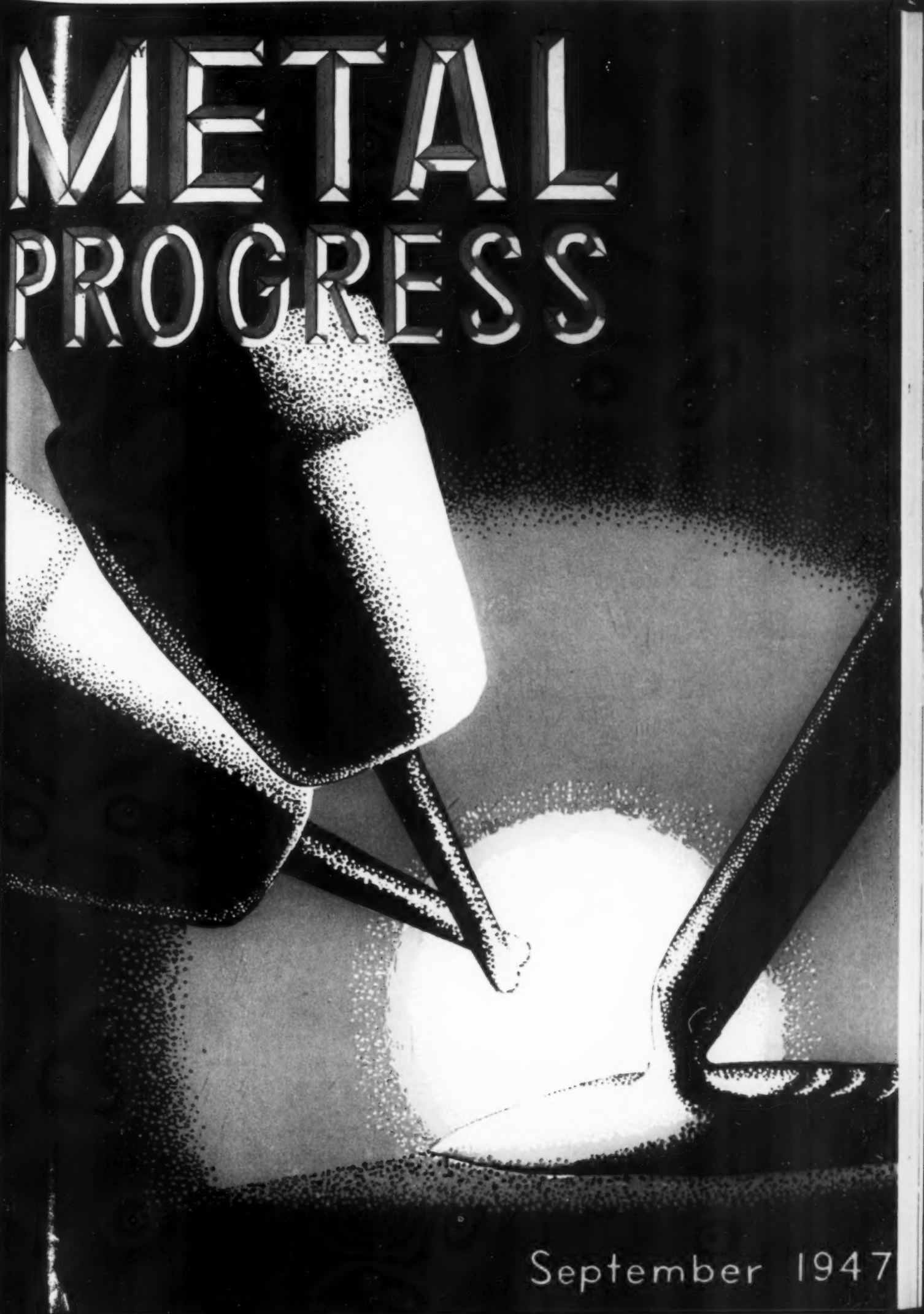

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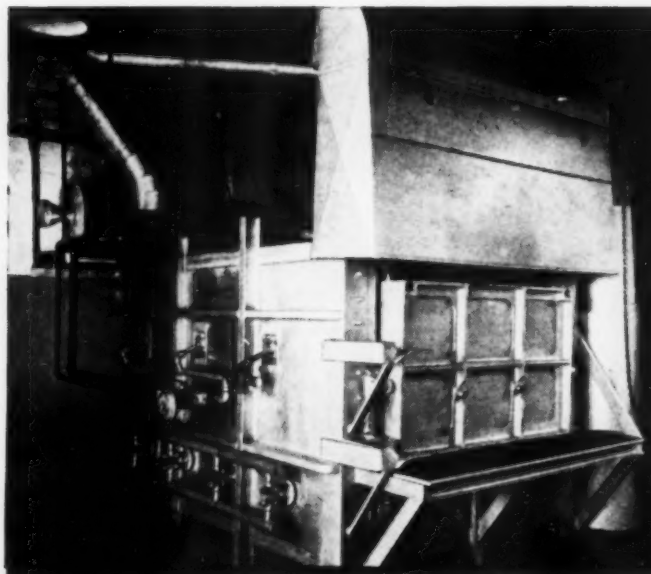

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DEMONSTRATES ITS VERSATILITY*

CARBURIZING • ANNEALING
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Steel: SAE 1020
Oper: Annealing
Temp: 1600°F.
Time: 36 hours
Charge: 6400 lbs.

***Part: Trailer Jack Screws**
Steel: Malleable Iron
Oper: Malleableizing
Temp: 1750°F.
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Atwood Vacuum Machine Co., manufacturers of automobile and implement parts, use this 'Surface' Conjecto-Fired, Standard Rated, Large Oven Furnace for their efficient, economical pack carburizing, annealing, malleableizing and other heat treatments. For complete description of the furnace shown above write for Bulletin OG-45 and Specification LO-45.

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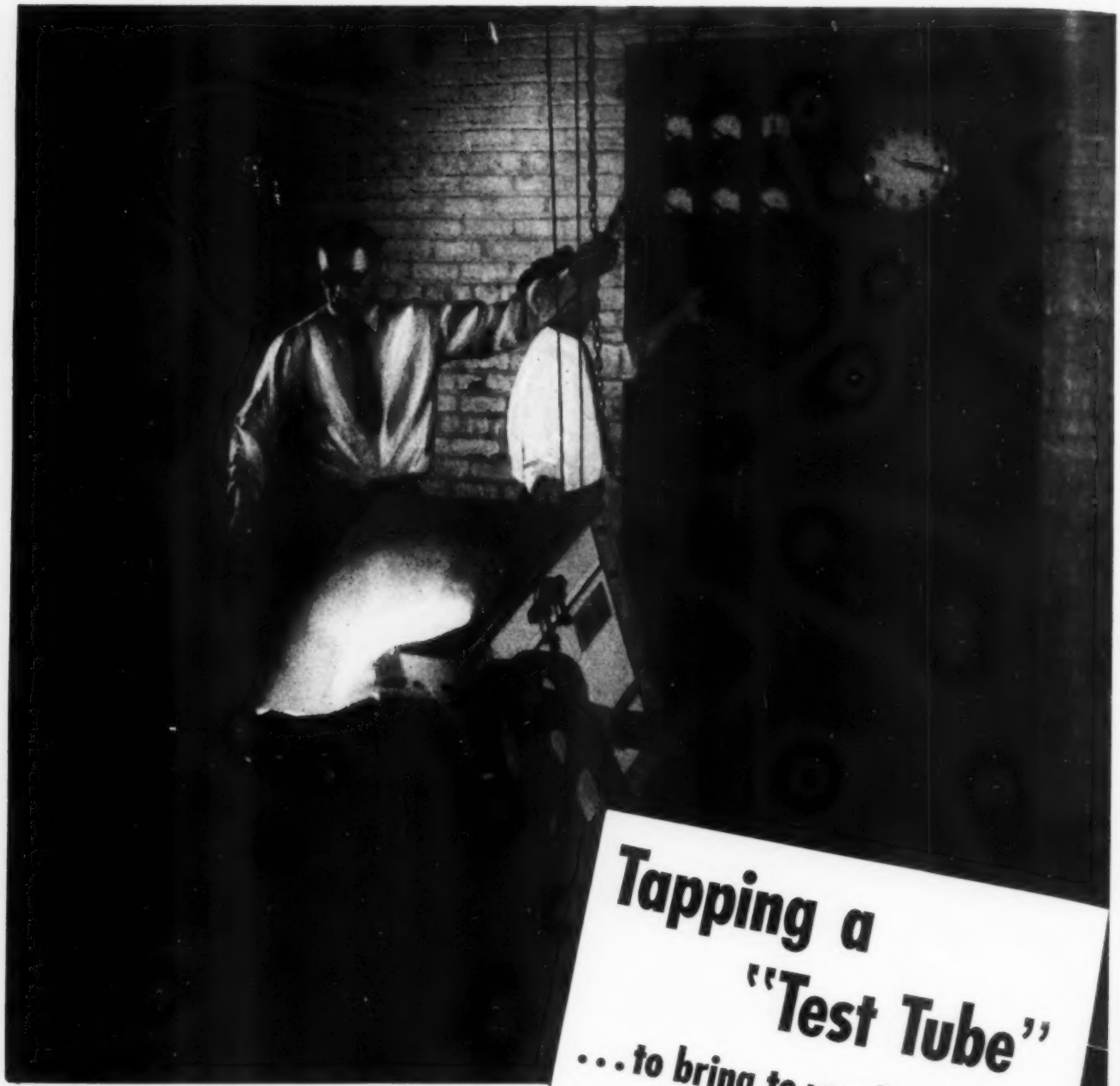

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Graphitization of Steels at Elevated Temperatures

By Albert E. White
Past-President,
Director of Engineering Research
University of Michigan, Ann Arbor

A tendency for carbide to graphitize in steel pipe and fittings in high-pressure steam systems, discovered in 1943, has been combatted by specifying coarse-grained structure in the pipe — which prevents the steelmaker from deoxidizing the melt with aluminum, the greatest single promoter of instability of carbide — and by adding chromium to pipe, castings and forged fittings for promoting stability of carbides. Graphitization is apparently not as serious a hazard to safe operation as it appears to the microscopist or metallurgical theorist.

IN JANUARY 1943 a failure occurred in a large central power station in a carbon-molybdenum steel steam pipe adjacent to a weld. This station was operating at a steam temperature of approximately 935° F. Upon examination of the pipe, graphite was found in the failed area, which was at the outside edge of the heat affected zone of a weld. The failure was felt to be due to the graphite which had formed and segregated in this area, with parts of it of a chain-like type.

These findings were considered of sufficient importance so that a conference was held in Pittsburgh the latter part of March 1943. The conference was attended by representatives of the power plant industry and those interested in piping for high-temperature purposes in other fields, as well as those engaged in the production and fabrication of pipe.

Following this meeting, many of the power plant interests represented at the conference began investigating their piping systems to determine whether or not graphitization was occurring. Of approximately 40 companies that made this examination, about half found graphitization in varying degrees. Later, a number of extensive studies of the phenomenon of graphitization were made by pipe mills, pipe fabricators, and a few of the central station companies, among which were the Philadelphia Electric Co.; The Detroit Edison Co.; Consolidated Gas, Electric Light and Power Co. of Baltimore; and the Public Service Co. of N. J. Also, an intensive study of the problem has been made at Battelle Memorial Institute under the joint sponsorship of the Edison Electric Institute, the Assoc. of Edison Illuminating Companies, and several steel casting companies engaged in the production of valves for high-temperature service.

The graphitization that has been observed may be described as of three types — *(a)* chain graphite; *(b)* segregated graphite, which in numerous instances is of a semichain-like type; and *(c)* nodular graphite. These are shown in Fig. 1, 2 and 3, each consisting of a photomicrograph at 100 and 1000 ×, respectively. At low magnifications the chain graphite might easily be mistaken for a boundary crack.

Only one or two installations have been found to have a pronounced chain-like type of graphitization (Fig. 1). Some might view the structure shown in Fig. 2 as of that type, but a supplementary examination developed that the graphite had no continuous appreciable depth. A photomicrograph taken from a plane 0.001 in., or even less, below that from which this photomicrograph was taken would not show graphite directly below the

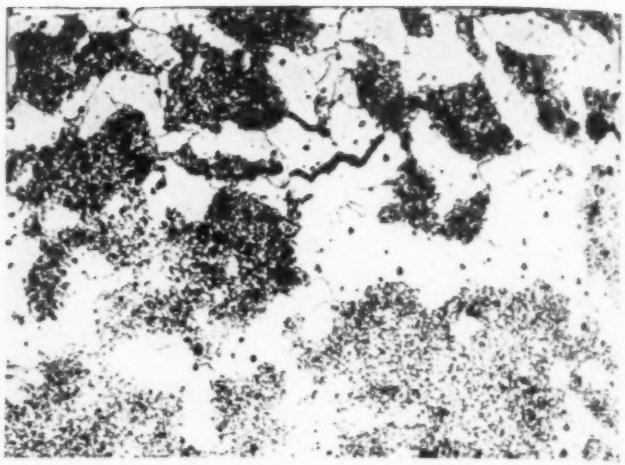


Fig. 1 — Severe Chain Graphite (1000 and 100 ×) at Low-Temperature Edge of Heat Affected Zone of Weld in Carbon-Molybdenum Steel Pipe After 5½ Years at 935° F. Nominal Operating Temperature

stringer brought out in the original plane. Graphite would be present in the new plane, but not directly connected with that found in the plane from which the companion photograph was taken.

Furthermore, the intensity of the graphitization varies around the circumference of the pipe, for graphitization may occur in certain pipe segments while in others it may be absent.

As yet, it is not certain whether the segregated graphite of Fig. 2 represents early stages in the development of chain graphite or merely indicates a discontinuous nodular formation characteristic of the material. Segregated nodular graphite has sometimes been found with chain graphite.

Plain nodular graphite of general distribution (Fig. 3) has not been of great concern. The principal disadvantage of its presence is the disquieting knowledge that the steel is subject to graphitization and at some point in the system conditions *may* be favorable for the formation of chain-like graphite.

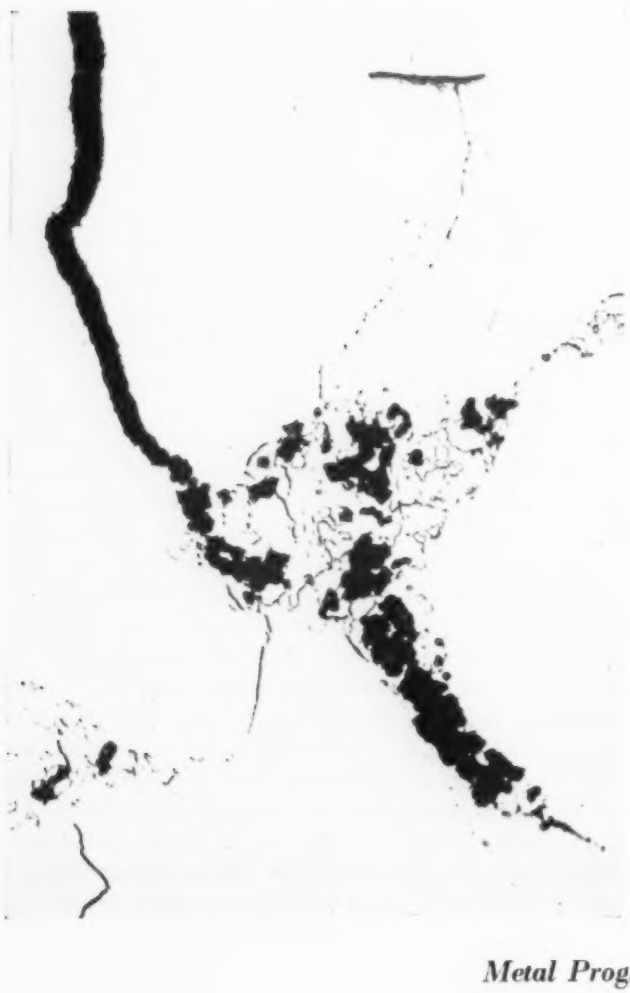
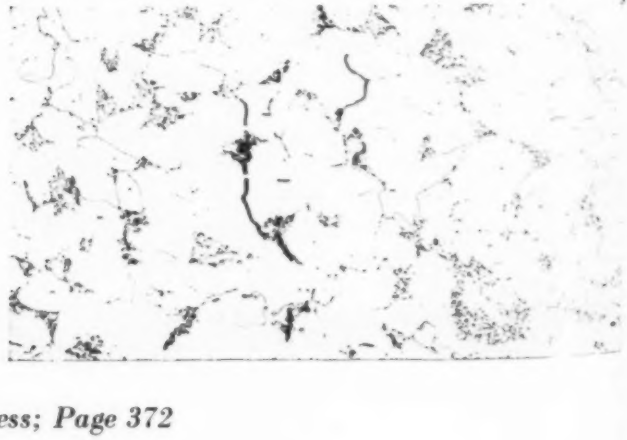
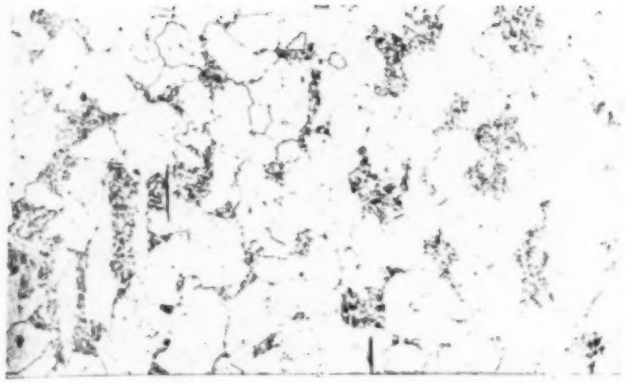


Fig. 2 — Segregated Graphite at the Edge of a Heat Affected Zone in Carbon-Molybdenum Steel Pipe After 50,600-Hr. Service at 900° F. (1000 and 100 ×)





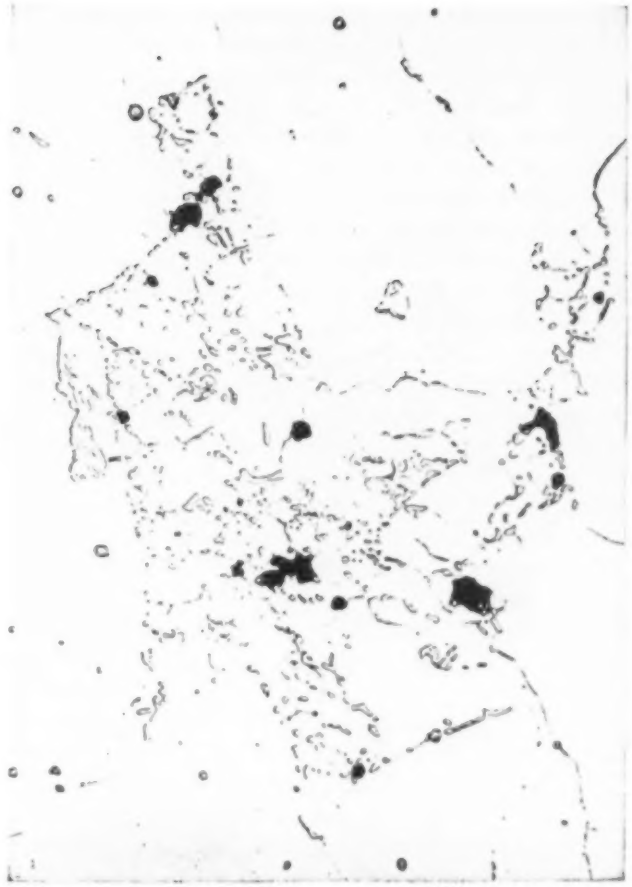


Fig. 3 — Example of Nodular Graphite at the Low-Temperature Edge of the Heat Affected Zone of a Weld in Carbon-Molybdenum Steel

If one were to evaluate the hazards resulting from graphitization solely on the basis of photomicrographs, especially those at 1000 diameters, one would doubtless be greatly concerned. One must realize, however, that the sections which are viewed are very greatly enlarged and that in most instances the graphitization is not continuous with respect to any plane.

Factors Affecting Graphitization

Naturally, those using metals at high temperatures would prefer that graphitization did not occur. Various causes besides those of time and temperature have been advanced to explain its formation. The *fundamental* reason, of course, is that graphite is the most stable form of the carbon in steel; the combined form (cementite, Fe_3C) is "metastable" as defined thermodynamically. The problem, then, has been to determine the factors which so unexpectedly resulted in the breakdown of the carbides to graphite ($Fe_3C \rightarrow 3Fe+C$) at temperatures around 900° F. during a heating time of 20,000 or more hours. The numerous studies which have been made of the service records and the experimentally accelerated investigations have fairly well established the following factors and their effects, although the fundamentals are not as yet understood:

Fluctuating Temperature — In some instances it has been thought that fluctuating temperatures, particularly during service, contributed to the formation of graphite. This may be a factor, although graphitization has taken place in metal when under constant temperature conditions.

Upsetting — Upsetting has also been advanced as a cause of graphitization. It is probably a factor, due to its effect on grain size and the possible stresses that may be set up in upsetting, but it is generally believed that it can be construed only as a contributing cause.

Table I — Chemical Specifications for High-Temperature Pipe and Fittings (A.S.T.M.)

	Seamless Pipe		Castings		Forged Flanges	
	C-Mo	Cr-Mo	C-Mo	Cr-Mo	C-Mo	Cr-Mo
Carbon	0.10 to 0.20	0.10 to 0.20	0.35 max.	0.30 max.	0.35 max.	0.15 to 0.25
Manganese	0.30 to 0.80	0.30 to 0.60	1.00 max.	1.00 max.	0.30 to 0.80	0.40 to 0.60
Phosphorus	0.04 max.	0.04 max.	0.05 max.	0.05 max.	0.04 max.	0.04 max.
Sulphur	0.05 max.	0.05 max.	0.06 max.	0.06 max.	0.05 max.	0.05 max.
Silicon	0.10 to 0.50	0.10 to 0.30	0.20 min.	0.75 max.	0.20 to 0.50	0.45 to 0.75
Molybdenum	0.45 to 0.65	0.45 to 0.65	0.40 min.	0.45 to 0.65	0.40 to 0.60	0.60 to 0.80
Chromium	—	0.40 to 0.60	—	1.50 to 2.25	—	1.50 to 2.00

Service Stress — The effect of stress on the metal during service has been advanced as a cause. This may be an appreciable factor, as it is understood that in one of the plants in which pronounced graphitization occurred the pipe was under excessive stress.

Initial Graphite Nuclei — The presence of initial graphite nuclei has been advanced as a cause. If these nuclei exist they may be a factor, but they are probably not the primary contributing cause of graphitization.

Heat Treatment — There seems to be no question but that repeated heatings of the steel to just above the A_1 temperature, as occurs during the welding operation, favor graphitization. Stress relieving treatments probably retard graphitization, at least when the temperature range for stress relieving is between 1200 and 1400° F.

Chemical Composition and Steelmaking Practice — The principal observation made has been that the use of aluminum in the deoxidation of the steels is the greatest single factor in promoting graphite formation. Practically all instances of severe graphitization observed in service or in experimental work have occurred in steel to which appreciable amounts of aluminum have been added with a resultant fine-grained structure and abnormality, as determined by the McQuaid-Ehn test. No generally accepted reason for the potent effect of aluminum has been advanced so far, although if more than from 1 to 1½ lb. aluminum is added per ton of molten steel, a strong graphitizing tendency results.

Beginning with 1939, the American Society for Testing Materials' specification called for a coarse-grained carbon-molybdenum steel because of its better high-temperature strength.* This meant that the steel had to be low in aluminum, although no such limitation was written into the paragraphs specifying details of steelmaking process. At the time this specification was written, no difficulties had been experienced due to graphitization. The coarse-grain requirement, therefore, was for the production of a steel which would have better high-temperature strength and not for the production of a steel which would resist graphitization. As a result of this change in the specification in 1939, most, if not all, of the steels purchased to A 206-39 T or later versions for power piping have shown no appreciable graphitization tendencies.

For example in A 206-46 T, "Tentative Specifications for Seamless Carbon-Molybdenum Alloy Steel Pipe for High-Temperature Service", paragraph 2(d)* reads: "When requested by the purchaser and so stated in the order, hot-finished pipe in the as-finished condition, in nominal sizes 3 in. and over made to schedules 140 and 160 [a relation of wall thickness to diameter set up by American Standards Assoc., and representing very thick walls], shall have a structural grain size which is predominantly 3 to 6 as measured on an A.S.T.M. grain size chart." In a footnote, "structural grain size" is defined as "the predominant grain as evidenced by ferrite grains, Widmanstätten areas, or pearlite patches."

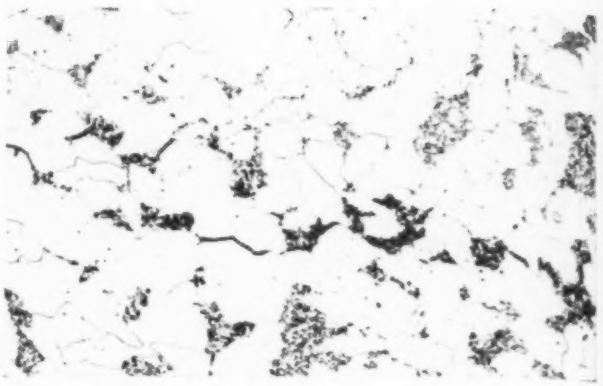


Fig. 4 — Severely Graphitized C-Mo Steel, 100 ×

The other elements in the steels have all been held in rather narrow limits by the specifications for these steels (Table I). No relationship has been observed between silicon, manganese, or residual elements (other than aluminum) and the tendency for graphitization. There is considerable evidence that chromium stabilizes the carbide. The minimum chromium content, however, has not been established, although it may be in excess of 0.5% for complete stabilization.

Restoration of Graphitized Sections

When pronounced graphitization has been found, the question has been raised if anything can be done to restore the metal to its original condition.

One investigation was conducted along the lines of heating the metal to 1700° F. for 2 hr. for the purpose of recombining the carbon in the form of graphite into carbide and then ascertaining the stability of this carbide. It is, of course, recognized that such a treatment is not practicable in all situations, because, when a graphitized area is adjacent to a valve, a heating of the metal to such a temperature as 1700° F. would result in warped valve sections. Also, of course, another possible disadvantage is that by heating the pipe metal to such a temperature a certain degree of scale would form on the inside, and if proper precautions were not taken, this scale might be carried by the steam to the valves or to the turbine, with resultant wear on valve seats or turbine blades.

Figures 4, 5, and 6 show the result of such an investigation; Fig. 4 shows the graphitized section, Fig. 5, the resultant after having been heated for 2

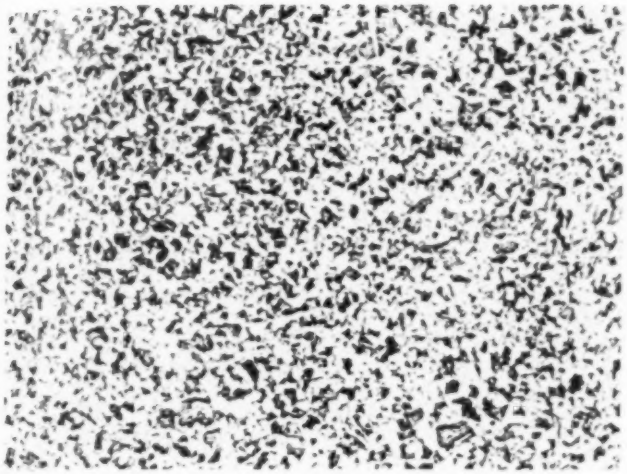


Fig. 5 — Steel of Fig. 4 After Heating 2 Hr. at 1700° F. and Air Cooling. 100 ×

hr. at 1700° F., with virtually complete conversion of the graphite to carbide, and Fig. 6, the result of heating this section for 2000 hr. at 950° F. after it had been stress relieved at 1300° F. It is noted that there is a slight manifestation of regraphitization — a result that was expected, for those who have thought of the solution treatment as a method of restoring graphitized pipe have not viewed it as a method that would result in a permanent cure.

Fig. 6 — Graphite Re-Formed in Steel of Fig. 5 After Stress Relieving 4 Hr. at 1300° F. and Holding 2000 Hr. at 950° F. 1000 ×

Trends

A great deal of attention has been devoted to finding an alloy which will not graphitize under the given service conditions. These service conditions are daily becoming more and more difficult to meet because designing engineers, in an effort to obtain greater economy, are going to higher temperatures. For instance, in 1943, the generally accepted high operating temperature was 925° F., with possible swings to 950°. Now plants are being designed for 950° F., with swings to 975°; some others are intended for 1000° F. operation, and three for operation at 1050 or 1100° F.

For the purpose of preventing graphitization for temperatures up to about 950° F., a steel with 0.50% chromium and 0.50% molybdenum was proposed. This has been embodied in an A.S.T.M. specification known as A280-46aT. Its composition is noted in the second column of Table I. No graphite has been found in this steel when produced in a steel mill to form pipe, even though it has been held for over 10,000 hr. at temperatures as high as 1100° F.

In studies which have been made on castings killed with 2 lb. of aluminum a slight degree of graphitization has been found at 1000° F. It is doubtful, however, if any detrimental graphitization would occur at 950° F., for even at 1000° the amount was not detrimental. Yet, in an effort to get away from *any* degree of graphitization, there is a trend in some quarters, for temperature service up to 975° F., to go to a cast steel with from 0.8 to 1.1% chromium specified, along with 0.5% molybdenum or from 1.0 to 1.5% chromium and 0.5% molybdenum. (The A.S.T.M. specification A157-44 for "Alloy Steel Castings for Valves, Flanges, and Fittings for High-Temperature Service" specifies even more chromium in grade C3A, as shown in the fourth column of Table I.)

Although the conversion of carbides to graphite has caused a considerable degree of concern to many power plants, there is a feeling that the dangers resulting from graphitization have been unduly stressed. Especially has this been true since certain physical tests have been reported in which entire sections of welded pipe, with considerable amounts of graphite in the heat affected zone, have been broken. In these tests, much to the surprise of those following them, the breaks occurred in the parent metal and not in the weld or in the heat affected zone of the weld — the zone in which the graphite was present.

Even though the problem does not appear as serious as was at first anticipated in some quarters, it behooves every company to keep a close check on the metals in their systems which have shown or are subject to graphitization.

Russell Hudson McCarroll

Metallurgical Engineer

in the Automotive

Industry

ON THE BANKS of the Rouge River in Dearborn, Mich., on the outskirts of Detroit, are acres of huge buildings housing the most famous manufacturing establishment in the world. Its chief product, the Ford car, is commonly seen literally in all corners of the globe; its name is a part of just about every language. Its history, inseparable from that of its founder, HENRY FORD, is known to every American schoolboy. Hardly a day passes without a newspaper reference to activities at the Ford plant.

What has created this wonder of the industrial age? Surely *men*, many men, all kinds of men, hard working, perspicacious men, hundreds, thousands of men doing the daily detailed tasks which add up to a successful enterprise. Of these men of accomplishment at Ford, one of the most outstanding (and one of the least willing to admit it) is a slender, soft-spoken but energetic gentleman, RUSSELL HUDSON MCCARROLL, in charge of research and chemical and metallurgical engineering. From his spacious but unpretentious office right in the plant, surrounded by mementos of projects old and new, "Hud", as he is known to his intimate associates, keeps track of the multitudinous projects under way in the more than 20 laboratories under his direction, supervises chemical and metallurgical plant control, and the specification of materials. Not content to let this responsibility be his entire contribution to industry, he finds time to serve many technical societies and is particularly active as a member of the technical board of the Society of Automotive Engineers (which is sponsor of the iron and steel committee). His immediate attentions are also engaged as a director of the Engineering Society of Detroit, a member of the agricultural research committee of the Detroit Board of Commerce, and of the board of governors of the Horace H. Rackham Research Endowment Fund of Michigan State College and director of American Foundrymen's Assoc.

Born in Detroit on February 20, 1890, HUD MCCARROLL attended University School and Central High School of Detroit, and received the degree of Bachelor of Chemical Engineering from the University of Michigan in 1914. After graduation he started working for the Solvay Process Co., but HENRY FORD, a friend of MCCARROLL's father, Canon JOHN MCCARROLL of Saint Paul's Cathedral, persuaded the young man to join his rapidly expanding operations at Highland Park. Thus, in January, 1915, was formed the stalwart group of R. H. MCCARROLL, FRED C. YOUNG, JOHN F. VANDERSEE and J. F. MCCLOUD — a group not to be severed until a few months ago when JOHN VANDERSEE, the oldest of them, retired.

MCCARROLL's early duties consisted chiefly of a study of plant problems involving such varying matters as car finishes, soluble oils, abrasives, and lubricants. So thoroughly did he throw himself into these tasks and so quickly did he absorb a vast amount of information that he was soon looked up to as an expert. The esteem in which he was held by his associates can perhaps be best expressed by the words of a gifted Chinese who was studying American industry: "If I, with my ability, also had MCCARROLL's experience, I really could go a long way!"

This tribute came to a young fellow only two or three years out of college.

When construction of the Rouge plant was nearing completion, MCCARROLL was given charge of chemical control of the various units as they went into operation, first the coke ovens, next the blast furnaces and the foundry. Here "Hud" really struck his stride. The Ford foundry was unique in that the blast furnace was an adjunct which supplied molten pig iron, so it was only a short step from chemical control to the metallurgical problems of the castings art. His quick grasp of the metallurgical problems involved soon made him constantly in demand and in 1925 he found himself in charge of all Ford's chemical and metallurgical research and control activities.

Foundry problems appealed to him particularly. He always approached them, then as now, with an open mind. He was always ready to modify chemical analyses or mechanical or molding methods to solve a problem. He organized groups of engineers and worked them intensively on special alloys and molding methods for cast steel crankshafts, self-hardened camshafts, gear blanks, pistons and many other innovations where castings substituted for forgings. Under his direction came forth an extensive development of the centrifugal casting method, culminating, during the last war, in the production of cast steel cylinders, cylinder barrels and other parts for tank engines and the Pratt and Whitney aircraft engine. Numerous patents were granted him for special steels, cast irons and malleable iron alloys, for centrifugal casting methods, and other metallurgical processes.

In speaking of these improvements MCCARROLL would be first to remind his hearer that no one person can accomplish very much alone. "In our type of work, one must first have a plan, then a staff, and finally an organization such as that in the Ford Motor Co., to attain any worthwhile improvements in industrial engineering," he recently wrote. "We not only have as fine a staff

as is available, but we also have an enthusiastic and cooperative manufacturing division."

His technical society affiliations include the American Society for Metals, the Society of Automotive Engineers, the American Chemical Society, and the Iron and Steel Institute. He has contributed many articles to professional journals. In 1936, the University of Michigan bestowed upon him an honorary degree of Master of Science.

Despite an arduous professional career, RUSSELL HUDSON MCCARROLL is a devoted family man. Shortly after graduation he was married to MURIEL C. CHANNER; they have two daughters, Charlotte Jane (Mrs. Charles R. Vincent, Jr.) and Marjorie. His main hobby has been his two grandchildren. As a fishing and small game hunting enthusiast he knows no peer, and his collection of fishing tackle rivals his technical accomplishments in profusion. Bridge and gin rummy provide relaxation. Not much time is found for golf these days but he is a member of the Dearborn Country Club of which he is past secretary, treasurer and president. As a reasonably good Sunday golfer, he has shot in the eighties.

Thus, in RUSSELL HUDSON MCCARROLL, still vigorously expanding the art and science of metallurgy, even though he has several normal lifetimes of accomplishment behind him, we honor an eminent American metallurgical engineer.

EUGENE V. IVANSO

Report of U. S. Atomic Energy Commission

IN the semiannual report to Congress (July 22, 1947) by the U.S. Atomic Energy Commission, Chairman Lilienthal emphasizes that "the Commission has pressed the production of fissionable materials and the improvement of atomic weapons as essential to the security of the country. The Oak Ridge, Tenn., facilities for separating the uranium-235 isotope are operating steadily. The production of plutonium is continuing at Hanford, Wash. The atomic weapons program is being carried forward at Los Alamos, N. M. The Commission is establishing proving grounds in the Pacific for routine experiments and tests of atomic weapons. The magnitude of the program has been fixed by the President, acting with the advice of the armed forces. We mean to maintain and increase the present pre-eminence of the United States in atomic weapons until such time as the Congress affirms that acceptable international agreements have been reached and the appropriate machinery has been established to insure that this activity can be relaxed without endangering the national security."

Aside from the continuance of the operations inherited on Jan. 1 from Manhattan Engineer District, the Commission reports much activity in reorganization (distribution of responsibility formerly centralized at Oak Ridge), in instituting a very broad program of fundamental research into atomic structure, and in such chores as accounting. Regarding the latter, not only does the Commission spend $550,000,000 per year — which involves sizable bookkeeping problems — but it must meticulously account for materials in process, and even for all documents (new and old) in the hands of all contractors.

Several remarks indicate that personnel problems are troublesome. The Commission owns completely and operates three large, isolated communities. Employees of the Commission or its contractor-operators number 45,600 (plus 900 army guards). Here are some remarks about professional and technical help:

"Severe shortage exists of physicians and biophysicists competent in the nuclear field. . . . The Commission has recently adopted the practice of making commitments in research contracts covering three years' salary of key scientists. Such commitments are expected to help attract and hold top caliber men. . . . The nation's supply of trained nuclear scientists and engineers is now woefully short. . . . Much attention is being given to attracting administrators, scientists and engineers of first-rate ability, and to retaining these men. Adequacy of salaries is being studied, as well as other conditions such as housing, retirement, and various professional working conditions."

The "labor" problem is also difficult and extends into the organizations of its contractors:

"Requirements as to continuity of operation, protection of restricted information, and Commission review of wage rates greatly restrict the area of free collective bargaining between management and employees. For the past six months the Commission staff and consultants in the field of labor relations have been engaged in studies of this problem. The goal is a new system of labor relations which will guarantee as many of the established rights of labor as is consistent with the national security."

Much work is being done on "health physics", defined as "knowledge of the potential dangers presented by fissionable materials, reactors, and fission products, and means of combating them. . . . From the outset it was realized that, unless proper safeguards were taken, unprecedented hazards to personnel would exist. Plutonium, for example, is toxic from a biochemical standpoint and is also radioactive; fission products are highly radioactive. Knowledge was meager, and wide margins of safety were

Presentation of verbatim extracts from important contemporary documents concerning atomic energy does

required. . . . Nevertheless, outstandingly safe working conditions have been maintained. Frequency of accidents among Commission and contractor personnel was only 3.32 for each million man-hours (60% below the national average for industrial employment). Significant advances have also been made in our understanding of the problems involved. Accomplishments include entirely new types of electronic health instruments for detecting radiations of several different degrees of penetrating power; improved techniques for the detection of early evidence of radiation damage to organisms; establishment of tolerance dosages of alpha, beta and gamma radioactivity of materials dispersed in air, in water, or on floors or benches; improved decontamination methods as well as methods for disposing of fission products."

In connection with a list of the Commission's own laboratories and the large number of universities that are conducting coordinated investigations, the report has this to say about the importance of the fundamental research it is vigorously supporting:

"The organized efforts of the war years were directed toward the practical goal of developing an atomic weapon. However, the properties of the elementary particles composing the nucleus are still nearly as little known as in 1940. The forces that hold the elementary particles together in a nucleus, the processes that occur when a nucleus changes its energy content or its electrical charge, the nature of the fission event itself, are still largely mysteries. To reach a satisfactory understanding of the atomic nucleus is perhaps the foremost task now facing the science of physics. It calls for theoretical work of the highest order of difficulty, and for experimental work of great ingenuity. It involves, at some points, the construction and use of large and expensive special equipment.

"The only immediate goal of this research on fundamental nuclear processes is increase of knowledge. It is not now a necessary step toward the building of an atomic bomb or a controlled nuclear chain reactor. These devices have passed from the research stage into the development stage. However, it cannot be forgotten that they had their beginnings in the fundamental studies of many years ago. From the activity of fundamental nuclear research may come the new findings and the new ideas which will make the present nuclear technology obsolete. To neglect the exploration of this path is to renounce the intention of progress beyond the horizons now visible. Failure to press this fundamental exploration is to yield this nation's pre-eminence in atomic energy and atomic weapons."

As to new and experimental reactors (ordinarily in the form of nuclear chain-reacting piles):

"At Argonne National Laboratory, located just outside Chicago, are two experimental reactors, one of which is graphite-moderated and air-cooled, the other being both moderated and cooled by heavy water. A third reactor, of unique characteristics, is now in the design stage. . . . At Clinton Laboratories at Oak Ridge, Tenn., is an air-cooled graphite-moderated reactor which produces nearly all of the 90 or more radio-isotopes now being distributed to approved investigators. . . . At Los Alamos is a low-power, homogeneous 'water boiler' reactor operated by enriched uranium in the form of a salt dissolved in water."

As to the production of atomic power:

"A central difficulty concerns the materials of construction. The materials that go into a reactor must have certain special nuclear properties; they must be almost completely free of certain contaminants; they must be appropriate to the mechanical design of the structure; they must withstand the intense flux of neutrons and radiations seething within the reactor; finally, they must resist corrosion by the cooling medium. The researches of the war years succeeded in finding materials which satisfied these stringent requirements well enough for the limited purpose at hand — that is, for water-cooled or air-cooled reactors operating at low temperature for experimental purposes or for producing plutonium. But power production with satisfactory efficiency and economy calls for much higher reactor temperature, much higher heat flow through the reactor structure, much higher fluxes of neutron and gamma radiation, and different cooling media. Every requirement on the construction material is tightened, and the range of materials from which a choice is possible is correspondingly narrowed. . . .

"It is speculative, at this stage of development, to estimate how long it will be until power production units feasible for large-scale commercial use will be available. Such power, when attained, will almost certainly supplement rather than supplant water power, and power derived from coal, oil and gas."

As to control and dissemination of information, the Commission notes that in the Atomic Energy Act the Congress requires — at present — (1) "no exchange of information with other nations with respect to the use of atomic energy for industrial purposes, and (2) that the dissemination of scientific and technical information relating to atomic energy shall be permitted and encouraged so as to provide that free interchange of ideas and criticisms which is essential to scientific progress." This requires a careful balance. "To over-confine today's knowledge is to stifle the development which would provide security tomorrow. A comprehensive record of the information developed in the atomic energy program is being assembled in 100 volumes. About half will be restricted for use only by authorized persons participating in the Commission's program. During the past year 1200 scientific papers have been declassified as conforming to carefully established criteria codified by a committee under chairmanship of R. C. Tolman; a large number have been published. As an illustration of the effectiveness of the declassification program, sufficient material on the fundamental theory of nuclear reactors has been declassified to permit elementary instruction in universities."

not imply that the Editor agrees with the opinions quoted, nor that they are expressions of A.S.M. policy.

Carbo-Nitriding of S.A.E. Steel Parts

By Walter H. Holcroft
Vice-President
Holcroft & Co.
Detroit

This well-received paper, read before a meeting of the Chicago Chapter in the Spring of this year, describes — from a practicing metallurgical engineer's viewpoint — the results achieved in the clean hardening of finished alloy steel parts with a light case and with minimum size change. The basic atmosphere is Class 302 (20% CO, 40% H_2 and 40% N_2), to which is added metered amounts of a hydrocarbon gas and ammonia. File hard, wear resistant surfaces can be achieved in fairly short times at fairly low temperatures.

CARBO-NITRIDING is defined as "a process of casehardening an iron-base alloy by the simultaneous absorption of carbon and nitrogen, by heating in a gaseous atmosphere of suitable composition, followed by either quenching or cooling slowly as required".* Carbo-nitriding is a natural outgrowth of gas carburizing and came about when a demand arose in mass production industries for the replacement of multiple cyanide pots.

Carburizing with gas instead of pack carburizing is, of course, not a new idea, but early installations were plagued with large deposits of soot. If decarburizing diluting gases were introduced with the hydrocarbon to avoid this, the control of the process became practically impossible.

Our organization was fortunate in attacking this problem first from the standpoint of carbon control. In the early 1930's we were studying it from both the theoretical and experimental side, and we proceeded to work out combinations of CO, CO_2, H_2, H_2O and hydrocarbon which would be in equilibrium with various carbon steels at different heat treating temperatures.

The knowledge thus obtained was applied in building two muffle-type furnaces in 1934 for hardening 0.60% C steel shafts finished before heat treating. These furnaces and gas generators are still in operation. The generators consisted each of an externally heated alloy retort filled with broken brick through which a mixture of gas and air was passed. The gas formed was dehydrated by refrigeration and then introduced into the furnace muffle to envelop the shafts being heated. This same atmosphere would restore carbon to a 0.60% C steel if unmachined surfaces of the steel had been slightly decarburized before arriving at the furnace.

We were next ready to consider light case carburizing — that is, to a depth of 0.005 to 0.010 in. at temperatures of 1500 to 1600° F. For this, controlled diluting gases which are not decarburizing are even more important than in deep case carburizing at higher temperatures. In 1935 we received orders for continuous muffle-type furnaces for hardening transmission gears that had previously been treated in cyanide pots. Microscopic examination of work from these furnaces, in comparison with the cyanided gears, showed case depths to be the same but the surface layers differed in appearance. We decided to add ammonia to the carburizing gas and thus carbo-nitriding was started. We naturally thought that we

*A.S.T.M. specification E44-43, "Standard Definitions of Terms Relating to Heat Treatment of Metals", prepared jointly by S.A.E., A.F.A., and A.S.T.M.

had something new, but we unearthed an 1883 patent issued to Joseph Gill (No. 283,999) which claimed "the process of treating iron or steel in a closed chamber by subjecting it to the action of hydrocarbon vapor and nitrogen supplied independently or together in regulated quantities".

Carbo-nitriding now covers a wide range of temperature, case and atmosphere variations, and furnace design. Continuous furnaces in operation today are of the muffle type or radiant tube type. A radiant tube furnace was built in 1941, which incorporated three methods of cooling, *(a)* oil quench, *(b)* atmosphere blast cool, *(c)* atmosphere slow cool.

At the discharge end of the heating chamber a tray-load of work is pulled out on an elevator platform. If it is to be quenched in oil the elevator descends, the tray is moved through the oil to another elevator and is brought up outside the furnace structure. (See Fig. 1, elevation.)

If an oil quench is not desired, the elevator is locked in the up position and dog rails move under the tray and move it sideways into a chamber extending at right angles to the main structure where it may be atmosphere blast cooled. At this place atmosphere gas from the chamber is blown through fin-type coolers and then through the work on the tray, a scheme which later became known as "gas quenching". If slow cooling is desired the blower is shut down and the tray moves progressively through the water-cooled section in the third leg of the furnace (which is laid out in the form of a U).

Other methods of quenching are in water, hot oil or hot salt. Each method gives a type of case which may be varied with the furnace temperature and atmosphere concentrations used. Immersion after quenching in deep freeze units sometimes has advantages.

The type of quench and furnace temperature may be determined by the amount of distortion allowable. At present, production furnaces operate from 1250 to 1650° F. In general, the lower-temperature ranges give cases similar in properties to those obtained by straight nitriding while the higher-temperature cases resemble those obtained by gas carburizing.

Many furnace types and mechanisms have been successfully used. The earliest ones had alloy muffles, heated externally by ordinary open-firing burners — and many of these are still operating. Our first radiant tube furnace with gas-tight steel binding was built in 1936. Rotary and batch types (radiant tube heated) have also been built.

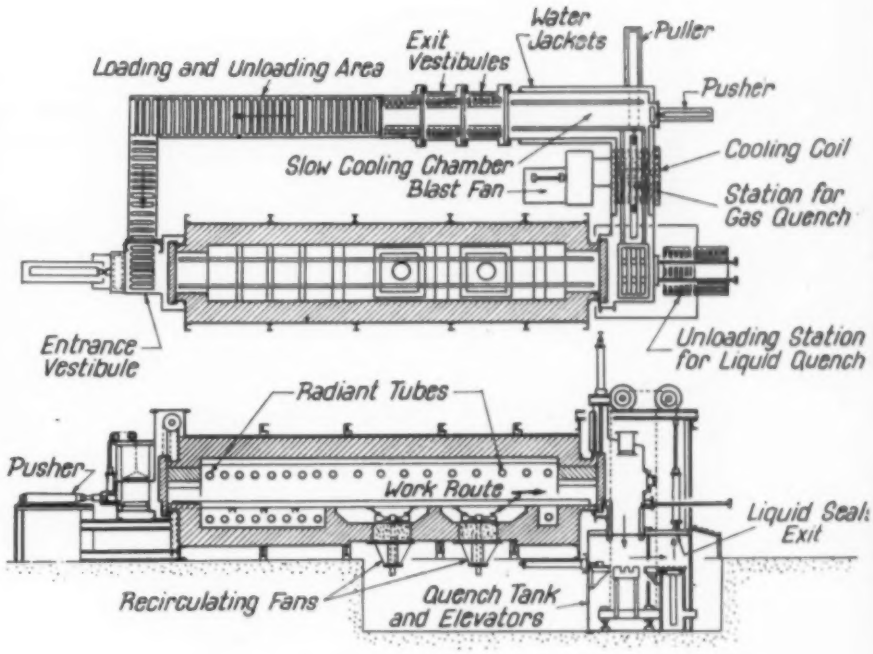


Fig. 1 — General Drawing of Continuous Carbo-Nitriding Furnace Heated by Radiant Tubes. The operator has choice of liquid quench, gas quench, or slow protected cool

The method or mechanism is immaterial as long as the fundamental requirement is met — that the hot work be immersed at all times in gas of the correct composition.

The atmosphere gas is a combination of three constituents, *(a)* generator gas, *(b)* hydrocarbon, *(c)* ammonia. Generator gas is obtained by passing a predetermined mixture of hydrocarbon gas and air through a heated retort filled with a catalytic material. It is gas of an endothermic base corresponding to American Gas Assoc.'s Class 302, and analyzes about 20% CO, 40% H_2 and 40% N_2.* A small amount of methane is also present (less than 1%), depending on the analysis of the fuel gas used, the temperature of the retort, and the nature of the catalyst.

In carbo-nitriding, sufficient generator gas is generally added to the volume being recirculated throughout the furnace to take care of losses through the entrance and exit vestibules. It may be regarded as a substantially nondecarburizing carrier. The action depends very much on the proportionate amounts of hydrocarbon (city gas, propane, methane, or any other available hydrocarbon of constant composition) and ammonia. Generally speaking, at higher temperatures more hydrocarbon gas is added to the furnace than at lower temperatures. The converse is true for the ammonia.

*See data sheet in last month's *Metal Progress* (p. 256-B); also article by Henry M. Heyn, starting on p. 232, describing generators and use of this Class 302 atmosphere.

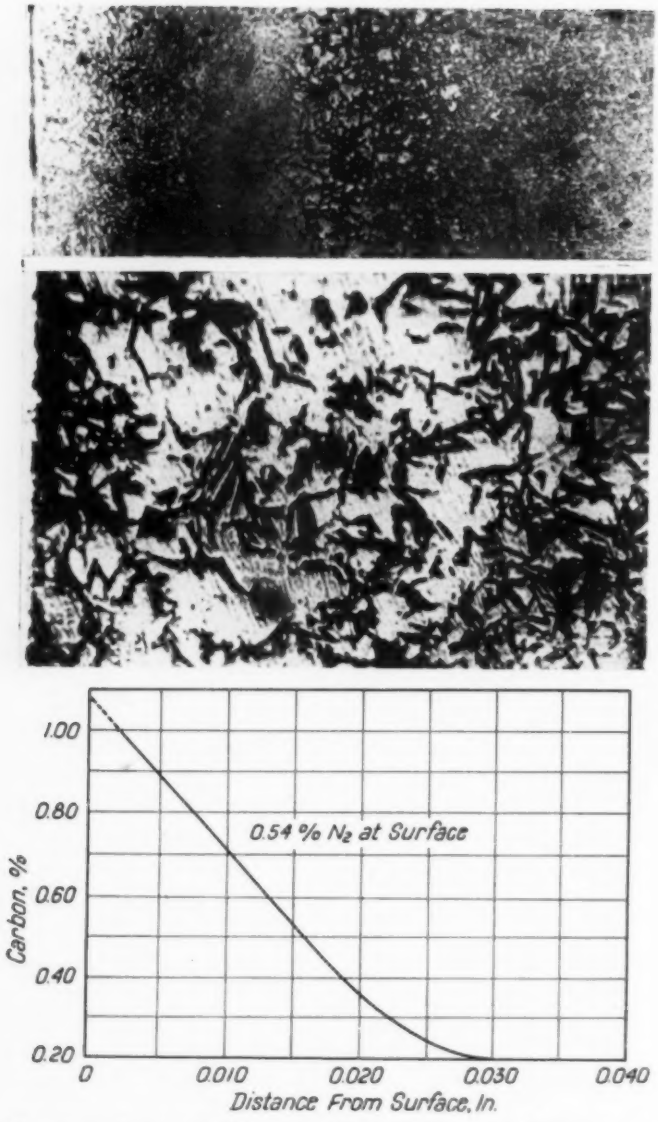
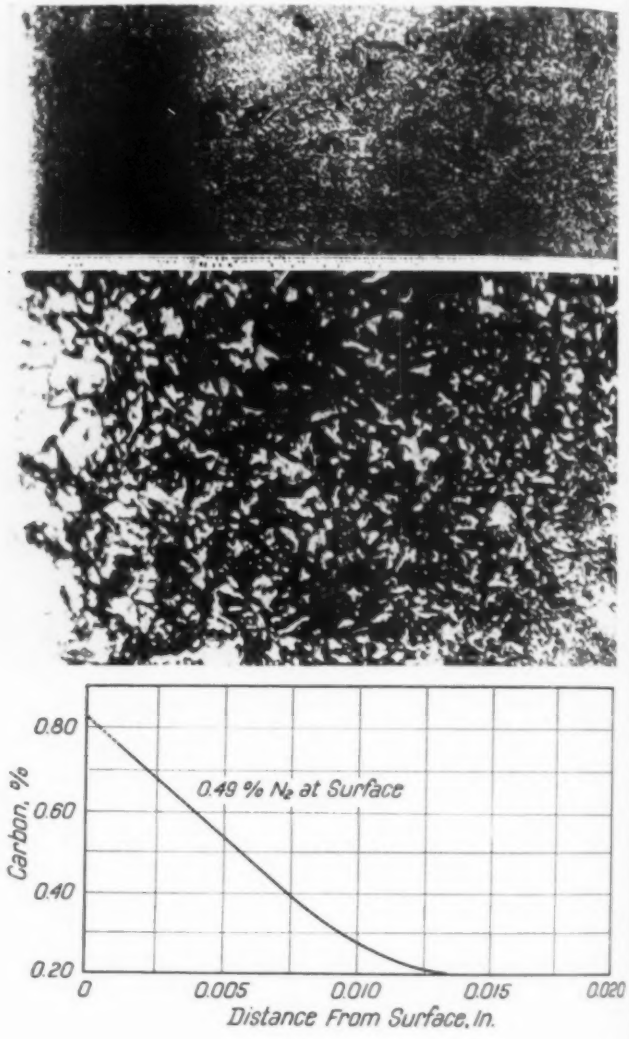


Fig. 2 — Case at 100 and 750 × From Radiant Tube Continuous Furnace. 3.6 hr. at 1640° F.; oil quench; 275° draw; C-62 hard. Gas make-up: 750 cu.ft. per hr. generator gas, 50 NH_3, 30 CH_4 (Detroit city gas)

Examples of Production Cases

Figures 2 to 7 contain photomicrographs at 100 × of the cases obtained by running 1-in. rounds of 1020 steel through as many different production furnaces. Each figure also contains a micro at 750 × of the outermost layer, thus giving a better idea of the fine structure. (All micros were etched with 4% nital. Hardness is converted to Rockwell C from 15N readings.) Likewise is shown a carbon-penetration curve for each sample, plotted from chemical analyses of successive cuts. Nitrogen content of outermost cut is also noted. Temperature, time, and atmosphere make-up is given in the respective captions.

Fig. 3 — Case in Sample From a Duplicate Furnace (Fig. 2). 2.4 hr. at 1520° F.; hot oil quench (340° F.); 445° draw; C-53 hard. Gas make-up: 900 cu.ft. per hr. generator gas, 35 NH_3, 25 CH_4 (Detroit city gas)



These pieces were run merely to give a comparison, on a standard piece, of what may be obtained with differing operating conditions. The microstructures shown are very close to what would be obtained on production pieces when the sample is oil quenched, but is not necessarily the same where the work is blast quenched or furnace cooled (due to difference in section and consequently in cooling rate).

The pieces shown in Fig. 2 and 3 were run through two identical furnace units, each consisting of an electrically-heated radiant tube atmosphere furnace, a quench tank provided with heating tubes, a wash and a draw. The samples were allowed to go through the complete cycle in a tray loaded with small parts. With loadings as dense as this, it is best to install recirculating fans in the furnace. This type of loading gives a

very uniform case. One unit was using the hot oil quench (sample in Fig. 3).

The piece shown in Fig. 4 was run through a muffle-type furnace, while that in Fig. 5 was put through a gas-fired radiant tube furnace. Pieces shown in Fig. 6 and 7 were put through muffle-type furnaces with water jacketed cooling ends attached. The furnace used for Fig. 6 has fans mounted in the cooling section; it also has fans mounted outside the furnace case which draw gas from the muffle and reintroduce it through holes in the rail section. This gives a positive motion to the gas through the sleeves being treated.

The low C-scale hardness of Fig. 6 and 7 is caused by the penetrator breaking through the very thin case (on the order of 0.006 in.) into the soft core. All the production parts processed at the same time were file hard.

As would be expected, the carbon and nitrogen content of the case decreases from the surface to the core. The depth of case varies with temperature and time, as in gas carburizing, and the carbon penetration rate seems to be the same as in gas carburizing.* The nitrogen appears to increase the hardenability of the case; consequently the effective, or hard, case obtained on quenching may be greater than in ordinary carburizing.

As can be seen from the data and microstructures, Fig. 2 to 7, large variations in type of case with different furnace conditions are possible, and the views illustrate results from but six furnaces out of 29 we have built and now in operation. Most of these furnaces are built for oil quenching and are used instead of salt bath cyaniding. Operating costs as low as one quarter that of cyaniding have been reported.

*See "Metal Progress Data Sheets" (1946) No. 67 and 68.

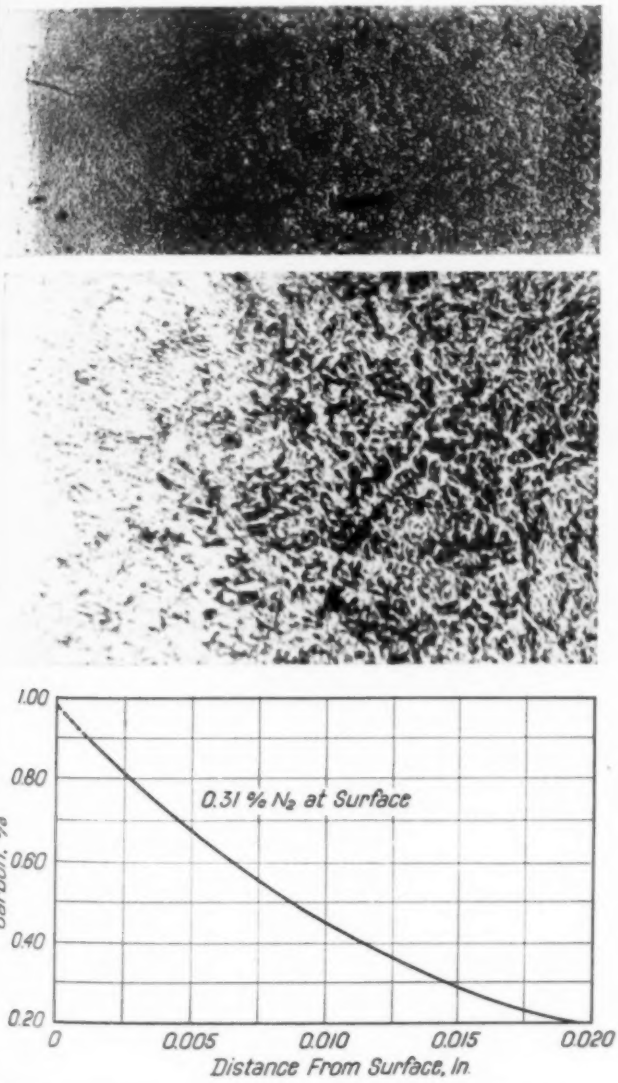
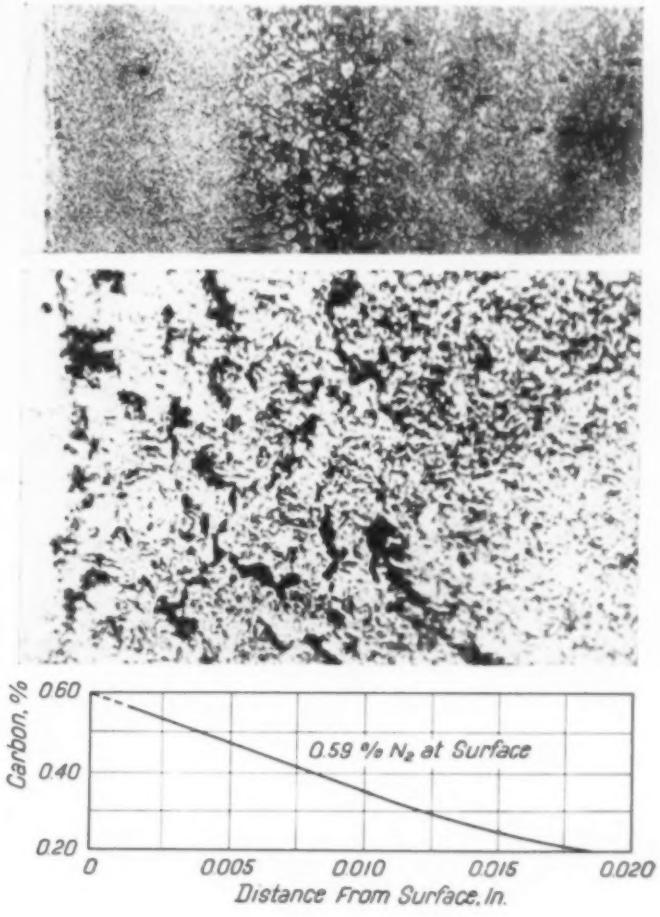


Fig. 4 — Case at 100 and at 750 × From Muffle-Type Furnace. 2.5 hr. at 1560° F.; oil quench; 350° draw; C-62 hard. Gas make-up: 750 cu.ft. per hr. generator gas, 48 NH_3, 24 C_3H_8

Fig. 5 — Case at 100 and 750 × From Gas-Fired Radiant Tube Furnace. 2.5 hr. at 1650° F.; oil quench; 350° draw; C-59 hard. Gas make-up: 1100 cu.ft. per hr. generator gas, 500 NH_3, 40 C_3H_8



Nitrogen Content of Cases

As can be seen from the captions of the figures, small amounts of ammonia are sufficient to give high surface hardness with oil quenching. This treatment quite often shows a large amount of retained austenite in the case; this type of case has a better wear life than straight carburized cases made by pack carburizing.

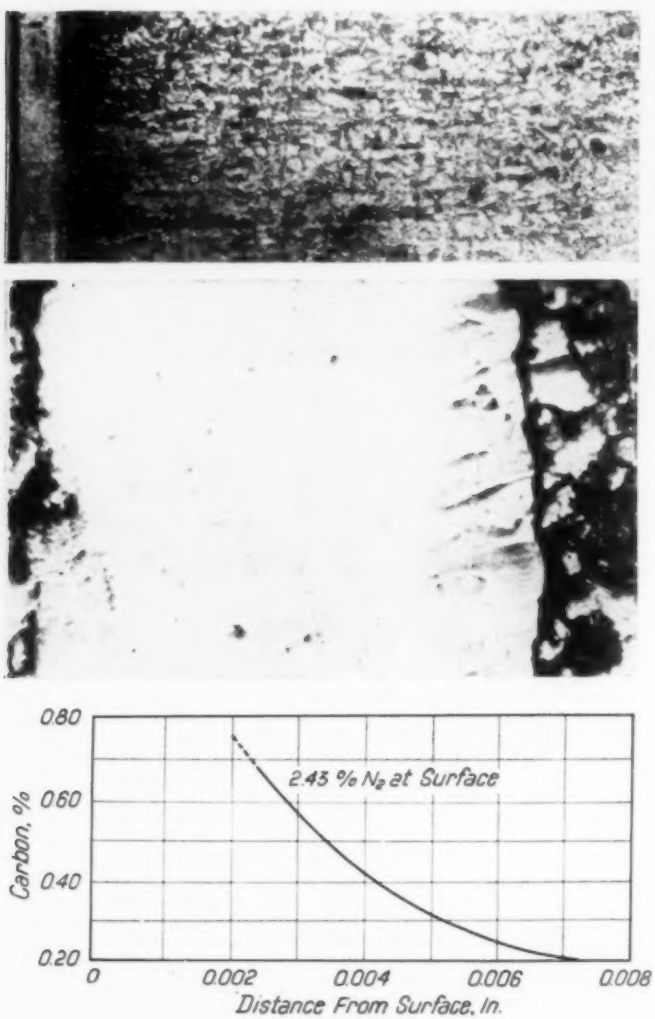
Atmosphere blast quenching and slow cooling are only used when more drastic types of quenching cause more distortion than is allowable. The ammonia requirements for the more slowly cooled pieces are increased and operating costs are consequently higher than with oil quenching.

When the operating temperature is below 1400° F. the case has a typical white layer which may have a tendency to spall. D. M. McCutcheon of Ford Motor Co. has given considerable study to this outer layer of case with X-ray equipment. He informs me that a spally case usually has a constituent in which a body-centered cubic lattice is predominant (thought to be a ferrite solid solution of nitrogen). Cases which are not spally usually contain both hexagonal close-packed and face-centered cubic constituents. High ammonia atmospheres are necessary for the type of case which does not spall.

At operating temperatures above 1400° F. a white layer is formed which may or may not contain the constituents mentioned above, yet it does not have a tendency to spall, regardless of quenching method.

The physico-chemistry of carbo-nitriding is very similar to that of gas carburizing and consists of two essential steps: First, raise the carbon

Fig. 6 — Case at 100 and 750 × From Muffle-Type Furnace With Recirculating Gas and Water-Cooled Ends. 2.3 hr. at 1390° F.; semi-blast cool; not drawn; C-31 hard. Gas make-up: 1600 cu.ft. per hr. generator gas, 3200 NH_3



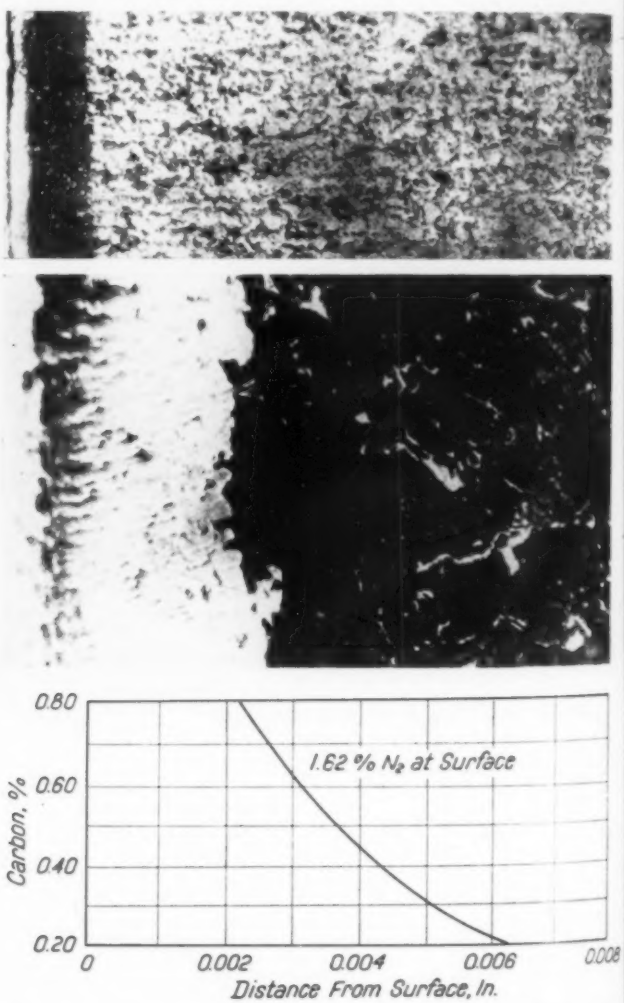


Fig. 7 — Case at 100 and 750 × From Muffle-Type Furnace With Water-Cooled Ends. 2.3 hr. at 1360° F.; furnace cool; not drawn; C-28 hard. Gas make-up: 480 cu.ft. per hr. generator gas, 52% NH_3

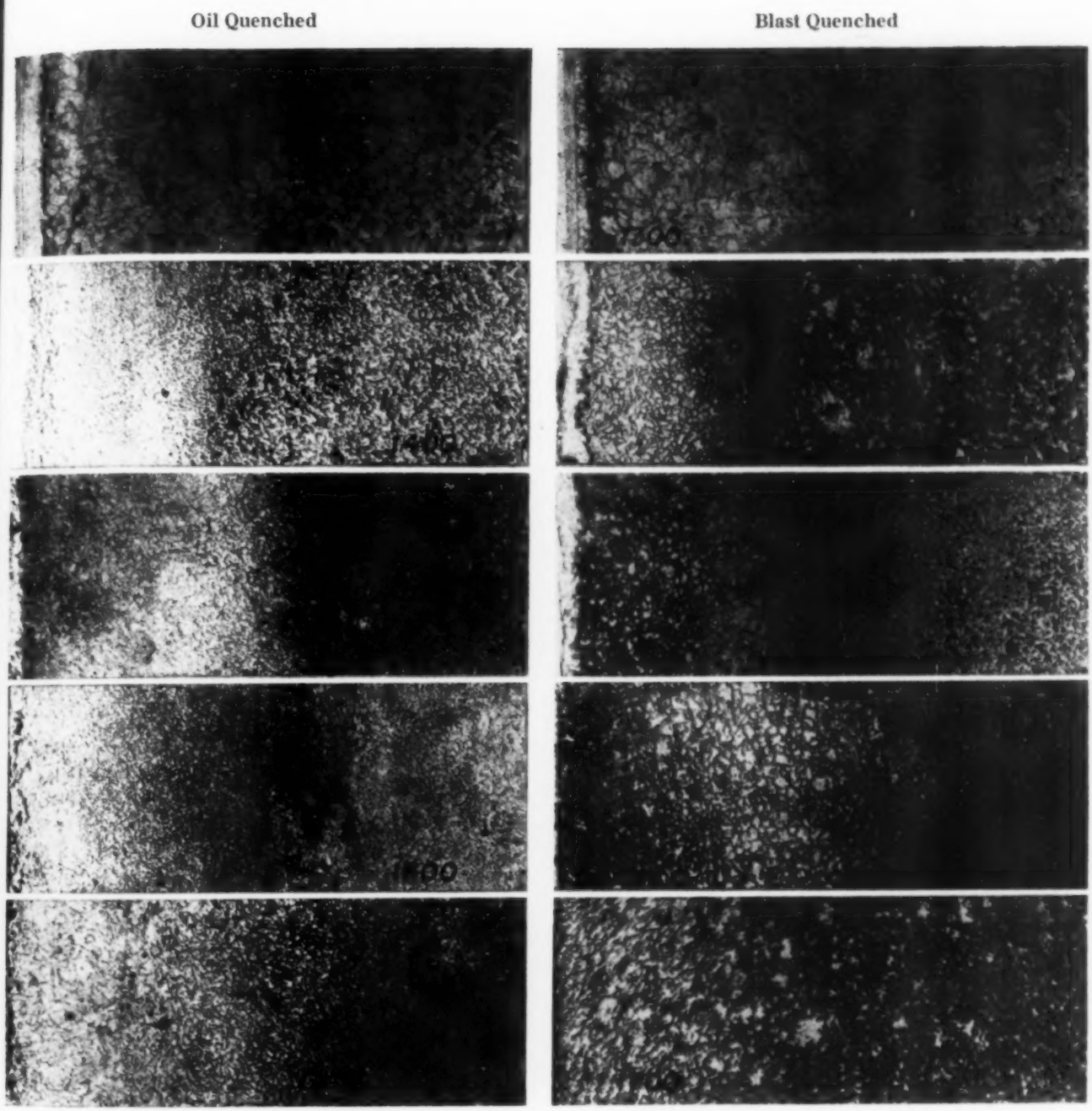


Fig. 8 — Laboratory Tests on S.A.E. 1020, ½ Hr. at Temperatures Noted, Either Oil Quenched or Blast Quenched. 100 ×

and nitrogen concentrations of the surface of the steel; second, diffuse the carbon and nitrogen into the body of the steel.

With respect to the second step it is fairly well established that the depth of case is a function of time and temperature although, as previously mentioned, the hardenable case may be greater due to the nitrogen addition. For the first step it is necessary to supply carbon and nitrogen at the surface of the steel — preferably with a controlled gas that may be varied to give different carbon and nitrogen concentrations at the surface of the steel, as may be required for different applications.

The chief source of nitrogen is ammonia gas, while the chief source of carbon at higher temperatures is hydrocarbon gas such as natural gas or propane, and at lower temperatures it is the carbon monoxide and unreacted hydrocarbon from the generator gas.

It is our feeling that the full scope of carbonitriding as an efficient, modern heat treating operation, capable of producing hard surfaces of desired characteristics, has not as yet been examined. Consequently, Holcroft & Co. is now running a series of laboratory tests under various conditions of flow, time, temperature and quenching media. Each series of these tests comprises runs made from 1300 to 1700° F. at 100° F. intervals, with the time ranging from 1 to 4 hr. at heat, and with both blast quenching and oil quenching. Each series of tests, therefore, means the examination of 40 specimens. For any one series of tests the flow of gaseous media to the furnace is maintained rigidly constant, both as to volume and composition. For different series one of the three gaseous media — that is, generator gas, enriching gas or ammonia — is varied.

Results of one test for 4 hr. at heat and the varying temperatures and quenching are shown in Fig. 8 at 100 ×. The tests were run in a vertical retort. Samples were S.A.E. 1020 steel $\frac{3}{8} \times \frac{3}{8} \times \frac{5}{8}$ in. The gas flow to the retort consisted of 20 cu.ft. per hr. of generator gas, 2.6 of Detroit city gas, and 5.0 of ammonia.

From these and other tests the following observations may be made:

1. A greater depth of white layer is obtained at lower temperatures.

2. The case depth bears the same time relationship as would be expected in normal carburizing in gas or compound.

3. At lower temperatures a distinct interface is obtained.

4. The nitrogen addition lowers the critical temperature (Ac_1) of the steel, allowing carbon to be added at 1300° F. (This is impossible in a normal carburizing treatment.)

All the oil-quenched samples were file hard. The air-cooled samples were file hard on the 1300, 1400 and 1500° F. runs.

Conclusion

In conclusion we can say:

1. Carbo-nitriding is cheaper than liquid cyaniding.

2. Greater depth of hardenable case is obtained in a given time than in carburizing.

3. Parts may be treated at low temperature and with slow cooling, thus minimizing distortion.

4. Both plain carbon and alloy steels respond to the process.

5. The process is not dangerous to personnel, as can be the use of fused cyanide salts.

6. Wear resistance is greater than with carburizing.

Book Review

REVIEW OF METAL LITERATURE, VOL. III, 1946. Prepared for members of the ASM by Battelle Memorial Institute, Ralph H. Hopp, librarian. 811 p., 6x9 in., cloth bound. Published by American Society for Metals, Cleveland 3.

Reviewed by Emory C. Skarshaug

Research Librarian, Federal-Mogul Corp.

THE THREE volumes of this title to date constitute a significant addition to the reference literature of metallurgy in the broadest sense of the term. The abstracts and annotations are first published in the monthly issues of *Metals Review*, thus making this combined service, to our knowledge, the most timely and prompt publication in the world in its field.

From thence the material is made up into the annual volumes, and adequately indexed.

Of journals whose articles are listed and annotated, Vol. I covered about 170, predominantly in the English language. Volume III expands both in numbers and in cosmopolitan aspect, covering 288 journals; American 205 and 83 from 10 foreign countries. In view of the fact that foreign journals are still difficult to get, the *Review* is to be complimented on its increased foreign coverage, which moreover is being expanded continually.

Because of the ease with which one can get a statistical survey of the field from the Review of Metal Literature, we have been making some comparisons. The following table may be of interest:

	VOL. I	VOL. II	VOL. III
Journals abstracted	167	262	288
Total abstracts	4830	5322	5332
Abstracts per journal	29	20	18.5

This declining trend in postwar technological literature seems incredible, and we shall watch its future with interest and curiosity.

We should like to call attention to the fact that the person responsible for the editorial direction of this work is Mrs. Marjorie R. Hyslop, who is also the editor of *Metals Review*, although her name appears nowhere in any one of the three volumes; even the preface in each of the volumes is modestly and simply signed: American Society for Metals.

Between the Review of Metal Literature and the *Metals Review* the ASM turns out the most timely abstracting service in the world, to our knowledge, in the field of metallurgy; also this is the only service of its kind devoted exclusively and entirely to the field of metallurgy and all of its sidelines, both ferrous and nonferrous. Finally, through its membership services it reaches a clientele virtually impossible to cover by any other service.

Vacuum Melting and Casting of Beryllium

By A. R. Kaufmann
Assoc. Prof. of Metallurgy
and E. Gordon
Research Metallurgist
Mass. Institute of Technology, Cambridge

*Vacuum melting and casting of beryllium was undertaken both for the purpose of refining the commercial metal of volatile constituents and for the purpose of making sound castings which could be used as such or which could serve as extrusion billets. The work was part of a program for the atomic energy project to study methods for increasing the ductility of beryllium.**

AFTER preliminary work on a laboratory scale on the problem of making sound beryllium castings, it was decided to use full size equipment so that methods, once developed, could be put on a production basis.

The melting furnace, shown in Fig. 1, consisted of a large quartz tube (12 in. inside diameter and 36 in. long). Insulation consisted of zircon bricks, 1 in. thick, which rested on a split graphite ring 2 in. thick, and all of this was supported on a quartz tube (10 in. inside diameter and 10½ in. high). The furnace top was made of steel and had a sighting window and shutter arrangement; the latter was also used to break up any distillate which condensed over the sighting hole. Two water-cooled copper plates for condensing distillate arising from the molten beryllium were attached to the top plate. A special shape made of graphite fitted into the condenser plates to shield the plates and to collect some of the distillate. The furnace bottom was a water-cooled shell (10 in. inside diameter and 6 in. deep) with a removable plate on the bottom.

The vacuum system consisted of a Kinney pump capable of pumping 100 cu.ft. per min. An oil filter was installed to catch finely divided particles which would foul the pump after a few melts. Piping was entirely of copper tubing with soft soldered, sweated fittings. A McCleod gage and a thermocouple gage were used for measuring the vacuum. Power was supplied by a 60-kw. high frequency motor-generator set (1920 cycles per sec.) to an induction coil surrounding the outer quartz tube.

Most of the beryllium metal was supplied by the Brush Beryllium Co. of Cleveland. It came in lump form and was so brittle that it could be broken up in an ordinary jaw crusher.

The first two lines of Table I give the results of quantitative chemical analysis of two samples and it can be seen that different lots of the metal are quite different in composition.

Crucible Materials — The first material to be tried as a crucible was graphite. It was found that beryllium, just above its melting point, reacted with graphite to form beryllium carbide, and that on continued heating the reaction proceeded quite vigorously. This resulted usually in the crucible being eaten away completely with resultant loss of the metal.

The graphite crucible and stopper rod were then coated with a thin layer of beryllia slip, but on heating to the melting temperature the coating was not adherent and it peeled off, exposing the crucible to attack by the metal. Increasing the

*This paper is based on work performed under Contract No. W-7405-eng-175 for the atomic energy project during 1944 and 1945 and the information contained therein will appear in Division IV of the Manhattan Project Technical Series as part of the contribution of the Metallurgical Project, Mass. Institute of Technology.

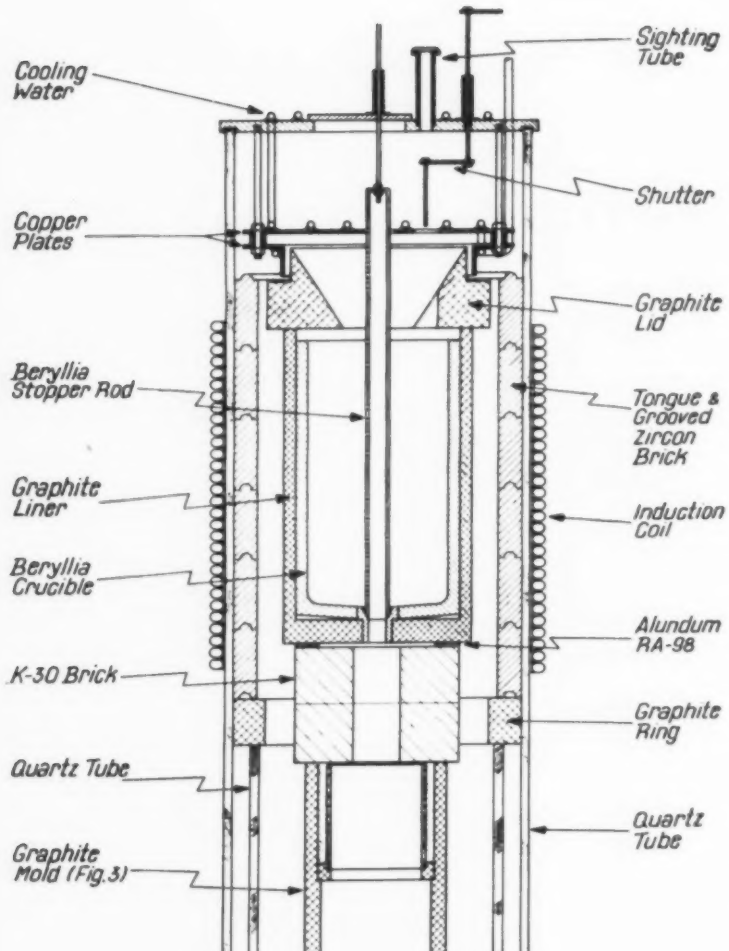


Fig. 1 — General Drawing of Furnace for Melting and Casting Beryllium. Scale: 1½ in. = 1 ft.

thickness of the coating was found to be so uncertain in results that the use of graphite for crucible and stopper rod was finally abandoned.

Melts on a small scale were made in crucibles of calcium oxide, zirconium oxide, aluminum oxide, zirconium carbide, and titanium nitride. Lime and alumina were found to react rapidly, and the other materials more slowly. Zirconium oxide seemed promising, since the zirconium pickup after 30 min. at 1400° C. (2550° F.) was fairly low. At best, none of these were really promising, and on the basis of a few melts made in small commercial beryllia crucibles it was decided to develop a beryllia crucible large enough to hold sufficient metal for a casting 4 in. in diameter and 6 in. long. It was also necessary that the crucible have good resistance to both thermal and mechanical shock.

The final size crucible (Fig. 2), 6 in. inside diameter, 12 in. high and with a ½-in. wall, was made by tamping a mixture of 50 to 200-mesh beryllia around a 6-in. round graphite mandrel, which was centered within a 7-in. inside diameter graphite crucible. A split sleeve of $\frac{1}{16}$-in. stainless steel sheet was placed around the mandrel during this operation, to facilitate removal of the mandrel. After tamping, the mandrel and sleeve were removed and the crucible fired within the graphite shell to 1650° C. (3000° F.) in a reducing atmosphere and held at temperature for 1 hr. A hole, ¾ in. in diameter, was drilled in the bottom and tapered to receive a stopper rod.

Along with the problem of developing a suitable crucible, it was necessary to make a stopper rod of the same specifications as the crucible. The first material used was a thermocouple protection tube made of alundum (Norton Co. No. RA98), coated with beryllia slip. This was attacked by the metal and usually broke after one or two melts. Next tried was a tube of alundum (Norton Co. No. RA1164), which was stronger and more dense than RA98. This was coated with beryllia slip and was found to last about five or six melts before breaking. The most satisfactory material was slip-cast beryllia tubing, closed at one end, 1 in. outside diameter and 18½ in. long, made by the McDanel Refractory Co. A hole was drilled through the closed end and a metal extension rod inserted and secured by lock nuts. These tubes were very good and could be used repeatedly.

Mold Materials — Both melting and casting were done in vacuum, cylindrical graphite molds being used at first. The shape of the desired billet was 4 in. diameter and 6 in. long; the mold was made 4¼ in. diameter to provide for shrinkage and poor surface, and 10 in. long to provide for the pipe. After using a mold once or twice it was found that the metal would react with the mold surface and be blown out of the mold. The surface of a billet made under these conditions

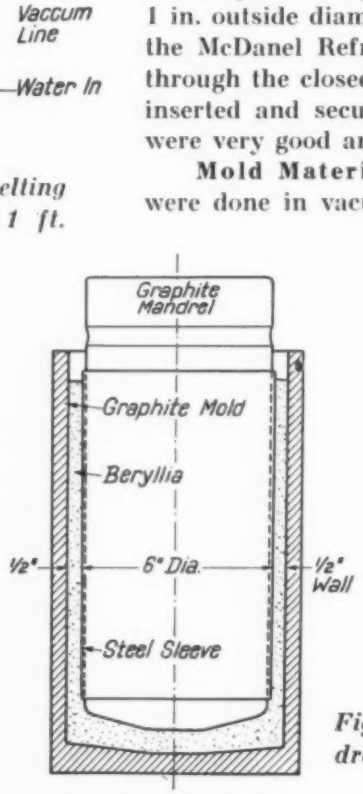


Fig. 2 — Mold and Inside Mandrel for Beryllia Crucible

Table I — Composition of Metal Before and After Vacuum Fusion

Lot	Treatment	Impurity, %										Method of Analysis
		Na	Fe	Si	Mn	Mg	Cu	Ca	Al	Cr	Pb	
A	As received	*(a)*	0.06	0.06	0.033	0.24	0.015	<0.01	0.27	0.005		Chemical
B	As received	<0.01	0.1	0.4	0.05	0.6	0.02	0.01	0.2	<0.01		Chemical
C	As received	0.01	0.1	0.4	0.05	0.6	0.02	0.01	0.2	0.01	0.01	Spectrographic
	After fusion	0.01	0.1	0.5	0.05	0.02	0.03	0.01	0.1	0.01	0.01	Spectrographic
D	As received	0.001	0.06	0.06	0.033	0.24	0.015	0.01	0.27	0.005	—	Chemical
	After fusion	0.001	0.03	0.01	0.007	0.01	—	0.003	0.05	—	—	Chemical
	After fusion	0.04	0.06	0.02	0.06	0.05	—	—	0.21	—	—	Chemical
	After fusion	0.01	0.036	0.02	0.008	0.02	0.006	—	0.04	—	—	Chemical
	After fusion	0.01	0.046	0.02	0.003	0.04	0.007	—	0.015	—	—	Chemical

(a) 0.001 ± 0.001%.

usually had several cold shuts and gas pockets.

To avoid these results the graphite molds were coated with beryllia slip and lined with beryllia paste, but showed no apparent advantage over untreated molds. Next, a mold of beryllia with a surrounding graphite sleeve was used and a sound billet was obtained, but since the cost and time involved were considered excessive other materials were tested. A copper mold with water-cooled copper bottom was tried but found unsatisfactory, since a low-melting beryllium-copper eutectic formed at the interface of the two metals. Mold coatings of carbon and beryllia prevented this somewhat, but not enough to give satisfactory results. A beryllia hot top was finally used with this mold, and this expedient resulted in a solid ingot 8 in. long.

A water-cooled steel mold with water-cooled copper bottom was next used, but some sticking and erosion were found on the bottom plate; an alundum disk, coated with beryllia slip, eliminated this difficulty. The same hot top arrangement was used and a full size billet with a fair surface was obtained, but the billet cracked internally and at the bottom because of too rapid cooling. Bottom cracking was eliminated by inserting a graphite cone to change the crystal growth; however, the internal cracks, as revealed by radiography, still persisted.

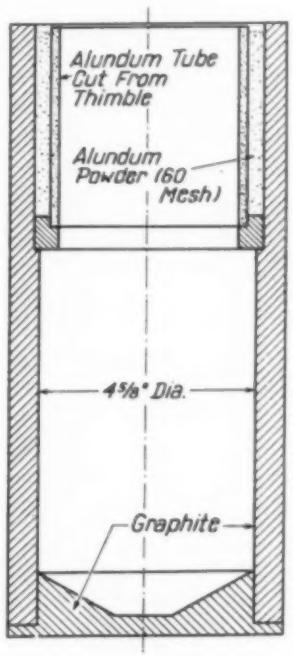


Fig. 3 — Successful Graphite Mold With Alundum Hot Top for Ingots 4.33-In. Diameter

Internal cracks were relatively infrequent in billets cast into graphite and therefore the use of metal molds was abandoned. In the experiments briefly described above, the crucible was placed directly on the graphite mold in the belief that the hot mold would reduce piping. Later, this arrangement was altered in such a way that the mold was separated from the crucible by 5 in. of K-30 insulating brick, as is shown in Fig. 1, thus keeping the mold much cooler. Also, after vacuum fusion and after most of the impurities had distilled off, argon was let into the system. The melt was then cast with 2 to 5 lb. positive pressure of argon. The combined use of argon and a cold mold gave the graphite molds a life of at least eight casts. In addition, the reaction which blew metal out of the mold was eliminated, and the surface of the billet was generally very good.

To insure good surface and improve on the yield of finished ingots, the mold diameter and length were increased, as shown in Fig. 3; the upper 4½ in. of the mold consisted of a hot top of alundum (Norton Co. No. RA84) cut from a thimble 3⅞ in. inside diameter and 4¼ in. outside diameter. Alundum powder filled the annular space between the crucible wall and the hot top. With proper amount of metal this gave an ingot which machined to 4.33 in. diameter and 6½ to 7 in. long. The yield of cast metal was generally about 90% of the furnace charge. The volume shrinkage of solidification was about 3%.

Casting Small Ingots

Small beryllium ingots, 2 in. diameter, were cast in graphite molds 2⅛ in. inside diameter and 17½ in. long, with a 4-in. diameter hot top of graphite. These were also cast with a positive pressure of argon. Although the casting had some secondary

pipe, it was satisfactory for the multiple 4-in. lengths which were desired. To eliminate the secondary pipe, a tapered mold was used with a 4-in. diameter hot top. First results showed this to be a satisfactory design.

Rods — Casting of rods, 1⅛ in. in diameter, of a 2% aluminum alloy was first attempted in graphite molds but resulted in internal holes, secondary pipes and poor surfaces. Multiple-holed molds with lengths varying from 7 to 16 in. also gave unsatisfactory results. This was followed by casting into alundum tubes (Norton Co. No. RA98), lined with beryllia slip and then surrounded by 60-mesh alumina powder (Fig. 4). In this arrangement the cooling period was too long, resulting in the formation of very large crystals. To eliminate this difficulty steel pipe was placed over the alundum tubes and this had the desired chilling effect. Six rods were cast simultaneously with a bulky riser or hot top, 2 to 3 in. thick. These rods were sound and had very good surfaces.

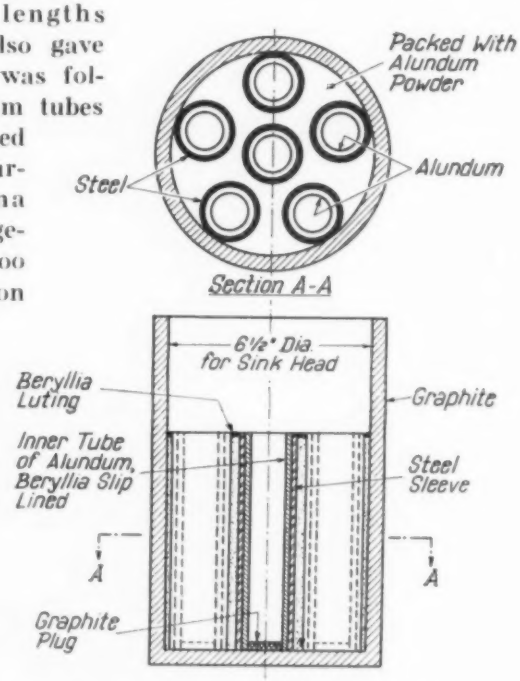


Fig. 4 — Multiple Mold for Casting Six Rods, 1⅛ In. Round

Melting and Casting Procedure

After assembling, the equipment was evacuated until a pressure of 80 to 100 μ was obtained. During heating, volatile materials were evolved from the impure beryllium, causing the pressure to rise to 200 or 300 μ, but the pressure would later decrease when the amount of distillation decreased. It was found on subsequent work that beryllium melts could be made successfully even at a pressure of 1500 μ, although this resulted in an excess of oxide skin left behind in the crucible.

As shown in Fig. 1, the beryllia crucible is located inside a graphite liner and concentric therewith. The graphite liner was heated by induction, and this in turn heated the metal by conduction and radiation. The graphite liner thus served to support the crucible and to heat it uniformly; it also facilitated the heating operation since beryllium, a good electrical conductor, did not heat very well by induction. In the normal operation the metal was brought to 1450° C. (2640° F.), the stopper rod lifted, and the melt teemed into the mold below.

The distillate which collected on the condenser and graphite lid analyzed from 25 to 30% magnesium, 6 to 12% beryllium, and 0.5 to 1% carbon, with a considerable amount of oxide. Between runs it was necessary to clean out the top of the furnace. The mixture of distillate was very explosive and this cleaning had to be done with the greatest of care.

The metal was considerably purified as a result of vacuum melting. This is shown in Table I. It should be noted that continued holding at temperature probably would further refine the melts. The crude metal, prior to vacuum melting, contains at least 5 to 10% of slag (mostly fluorides) and this is almost entirely removed. This improvement in quality is not revealed in Table I.

To insure that all castings were sound they were radiographed with a 150-kv. portable X-ray unit using a 1/15-in. aluminum filter. Intensifying screens were not used with the Eastman-type M film which gave optimum results. A current of 8 milliamperes for 1 min. and a distance of 36 in. from tube to film was standard for all sizes and the kilovoltage was varied for different thicknesses as follows:

Thickness	Kilovolts
1 in.	40
2	40 to 50
3	45 to 55
4	60 to 75
5	80 to 90
6	110

This work showed that beryllium oxide is the most satisfactory crucible material for melting beryllium metal in vacuum, and that large-sized beryllium castings can best be made with a medium rate of solidification. A chill casting will contain internal cracks, while slow cooling in a refractory mold will produce undesirably large crystals in the casting. Graphite makes a satisfactory mold material. It is also apparent that vacuum melting of beryllium will remove volatile impurities such as magnesium and magnesium fluoride, but will make little change in the iron, aluminum, silicon and copper content.

Correspondence

Hexagonal Slip in Beryllium Crystal

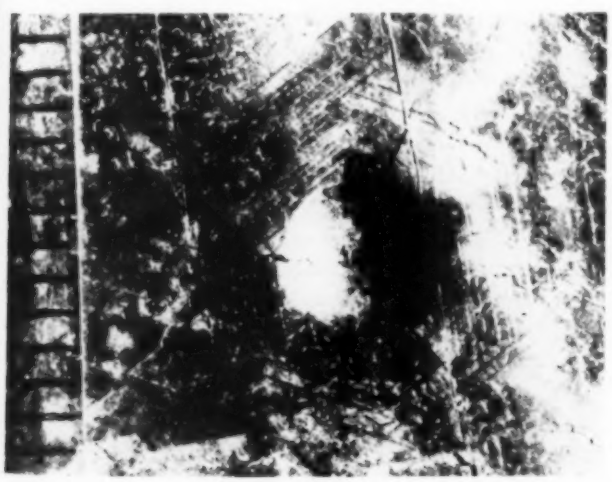
CULVER CITY, CALIF.

To the Readers of METAL PROGRESS:

The accompanying photograph shows slip planes forming an excellent hexagon about a Brinell indentation in a beryllium single crystal. To my knowledge, this interesting, rare phenomenon has not been recorded hitherto.

The millimeter scale at the edge shows the magnification to be five diameters. The crystal is part of a casting made from 99.5+% beryllium, with impurities divided among aluminum, iron, magnesium, silicon and carbon. The entire piece ($2\frac{1}{2} \times 1\frac{3}{4} \times 1\frac{1}{2}$ in.), cut from a larger casting, appears to be a single crystal, except for a possible mosaic structure.

The plane of slip in the hexagonal close-packed system is (0001), the plane of widest spacing and also the one most densely packed with atoms, while the three directions of slip in this basal plane are the $<2\bar{1}\bar{1}0>$ which contain the most closely packed rows of atoms.



The slip lines which form the hexagonal frame about the Brinell impression are parallel to the natural cleavage planes. Some of the latter appear as long straight lines on the face of the crystal. Several other Brinell indentations made on this face and on the crystal's opposite parallel face exhibited identical phenomena; the slip lines formed hexagons and each had sides parallel to the sides of all the others, regardless of the distance apart. However, Brinell indentations on the adjacent faces at 60 and 120° developed none.

There are also four major cracks, three straight and one jagged, radiating from the depression. The straight cracks are perpendicular to the slip lines, whereas the jagged rupture appears to be composed of two sets of cracks alternately perpendicular to two different sets of slip lines.

In view of the comparative ease with which large single crystals of beryllium may be produced, it is recommended that crystallographers and metallurgists interested in the properties of single crystals turn their attention to this element.

LESTER TARNOPOL
Consulting Engineer

Wire Cord Tires for Heavy Duty Trucks

JACKSON HEIGHTS, N. Y.

To the Readers of METAL PROGRESS:

The letter from Harry P. Coats describing in some detail the steel wires used instead of ordinary cords in Firestone's new heavy-duty tires reminds me that I personally, as far back as 8 years ago, mounted tires so constructed on heavy equipment and took a snapshot of the result. The tires were made by Michelin* (France) under the trade name "Métalic", and were adopted by the French ordnance on their road vehicles, not only for their long-wearing qualities but also for their resistance to puncture by directed or stray steel or other than loose bits of metal.

The tires on the light tank carrier shown in the photograph were inflated at 105 psi. Weight distribution was 15,500 lb. on front axle, 44,800 on rear bogie, gross loaded weight 30 tons.

My point is that in this respect the French, who have pioneered in many automotive developments, certainly beat Firestone "to the draw" in the matter of steel-corded pneumatic tires.

This also brings me to the article on "Torsion Bars for Springs" in the May issue. Citroen —

*Editor's Note — A 1947 Michelin road map showing main roads in Northern France still blocked by war damage notes "Michelin a créé le 1er pneu à carcasse métallique en 1938".

Bernard Truck Equipped With "Métalic" Michelin D24 Tires (Wire Cord), Inflated at 105 Psi., and Carrying a French Army's Light Combat Tank. Gross weight, truck and load, 30 tons, carried on 10 tires. Photographed in 1939

again French — *passenger* automobiles have been using four torsion bars, one for each wheel, since 1933. These are not isolated jobs; the monthly registration of new Citroen passenger cars in continental France averaged about 6000 in 1939.

While American scientists make an effort to recognize previous efforts when publishing the results of their investigations, American technical men seldom mention the original idea or realization, and American advertising men never. If this is merely a foible of the technologists it perhaps can be excused, or at least discounted; if it results from their ignorance about foreign progress, it is a more distressing situation.

A. A. Prevost
Technical Staff
Amer-Ind, Inc.

Slow Changes in Hardened Steel

Santa Monica, Calif.

To the Readers of Metal Progress:

In quoting C.A.A. statistics for 1945 airplane accidents, Mr. Kappel (see his letter in April *Metal Progress*) evidently did not have the detailed description of accident-cause listed by C.A.A. for each. As classified by C.A.A., "structural failure" includes brake failure, hydraulic system failure, landing gear collapse, landing gear retracting mechanism failure, and the detailed description of accidents classified as "structural failures" are replete with the foregoing terms. Rarely is a defective structural element associated with an assigned "structural failure". We see little relationship between C.A.A. classified "structural failures" and improperly heat treated structural elements.

We are interested, however, in Mr. Kappel's comments on the latter, which is the first to come to our attention about sluggishness of transformation in medium-carbon alloy steels. We should appreciate some additional comments on the amount of hardness increase he experienced with his subzero treatment, as well as a micrograph of the "mixed structure". The higher-than-specified hardness of the failed part may reflect rigidness of inspection rather than hardening during service at low temperature. Our own inspection of purchased heat treated steel parts has culled entirely too many units harder than specified.

L. Schapiro
Chief Research Metallurgist
Douglas Aircraft Co., Inc.

Titanium in Type 405 Stainless Iron

Niagara Falls, N. Y.

To the Readers of Metal Progress:

Mr. Scheil's paper on "Modified Type 405 Stainless Iron" in the July issue is a record of successful practical use of the aluminum-bearing type in long-time heat-resisting service, in spite of the instance of embrittlement mentioned by Mr. Newell in the April *Metal Progress*, and discussed at some length by Mr. Scheil. These two different reports regarding this same type of steel are not necessarily at variance with each other for two reasons — first, because it might be expected from the rather copious literature on the embrittlement of chromium steels that there would be a considerable difference in this respect between steels having the maximum and minimum limits of chromium and aluminum contents permitted by the specification; and secondly, because of the importance of the stress or design factor in failures of this kind, as noted in Mr. Scheil's Case F. In his statement that Type 405 linings in service since 1938 have given no indication of embrittlement, there is no assurance that low notch-bar impact values might not be found if such tests were now made; the design may merely have been adequate so embrittled material could serve well.

It is evident from the literature, including Mr. Newell's review as well as Mr. Scheil's article, that the embrittlement of chromium steels after long exposure to certain temperatures between 700 and 1000° F. is serious with higher-chromium ferritic steels, and disappears as the chromium falls below 11 or 12%. It is also well known that no alloy addition, except possibly manganese when present to the extent of about 3% or more,

decreases the embrittlement; it is also uncontested that ferrite-forming elements (such as silicon, molybdenum, aluminum, titanium, and columbium) *increase* it with lower chromium contents. Most of the latter elements decrease the hardenability of the steel, showing that there is no simple relation between hardening and embrittlement. Excess titanium is only one of several factors that might operate to promote this type of embrittlement of chromium steels.

The single instance of "excess titanium" given as "Case C", to support the author's suspicions regarding the natural connection between brittleness and a titanium content in this steel, is not conclusive when carefully examined. In view of the author's wide experience with this class of steel, his opinion that an important feature of the specification for this modified type is a very low limit for Ti and Cb deserves careful consideration. However, this particular steel also had chromium and aluminum close to the top limits of the specification, and fairly similar steels, such as in Table VIII, and on pages 97 and 102, are reported as brittle, even though they contain no titanium. Consequently, it does not seem sufficient merely to state that "the cause of this trouble was very definitely the titanium in the alloy". Proof is lacking that exactly the same steel without titanium would have stood the same service without embrittlement.

The important point to remember is that if *any* of the ferrite-stabilizing elements (Cr, Mo, Al, Ti, or Cb) are present in amounts near the maximum permissible, a little of any other of them may cause the balance to be upset and embrittlement result during service at 700 to 1000° F.

GEORGE F. COMSTOCK
Chief, Physical Metallurgy
Titanium Alloy Mfg. Co.

Manufacture of Lead Shot

SAN DIEGO, CALIF.

To the Readers of METAL PROGRESS:

In response to the Editor's query in his "Critical Points" in the June issue as to "Why Is a Shot Round?" and as to the physical action of the arsenic in the alloy, I would quote an abstract and summary of an article by G. Tammann and K. L. Dreyer entitled "Concerning the Form and Structure of Lead Shot" (*Zeitschrift für Metallkunde*, Vol. 25, 1933, p. 64):

"**Abstract** — In order to form spherical lead shot, arsenic is added to the lead; this addition removes the film of lead oxide, which would otherwise prevent the shot from becoming round, forming lead arsenite.

"**Summary** — The addition of arsenic, which is necessary for the making of round lead shot, changes the surface tension of the lead drop but little. It really removes the lead oxide layer from the shot by forming with it lead arsenite, which surrounds the lead sphere as a liquid film until the beginning of crystallization, and does not solidify until 200° C. has been reached. When the lead drop crystallizes several dendrites are always formed."

I have also in my possession a "Cabinet Encyclopedia" published in London in 1834. Volume III is subtitled "A Treatise on the Progressive Improvement and Present State of the Manufactures in Metal". It contains a rather detailed description of a shot tower, the methods of casting and grading the shot, and of removing the out-of-rounds, which in the fundamentals are the same as used a century later and described in *Metal Progress's* editorial note.

If any readers have other information of historical or scientific nature, the writer — who is now pursuing this inquiry as a hobby — would be interested in learning of it.

MERRITT A. WILLIAMSON
Director of Technical Research
Solar Aircraft Co.

Mythical Bird

SPOKANE, WASH.

To the Readers of METAL PROGRESS:

This synthetic Indian Thunderbird was found winging its way through a cast ingot of aluminum alloy 3S. (The constituent really is Al-Fe-Mn, and it was photographed at a magnification of 1800 ×.)

L. J. BARKER
Metallographer, Trentwood Works
Permanente Metals Corp.

Cobalt-Base and Nickel-Base Alloys for Ultrahigh Temperature

By F. S. Badger, Jr.
Vice-Pres. in Charge of Research
and F. C. Kroft, Jr.
Research Metallurgist
Haynes Stellite Co., Kokomo, Ind.

This paper was presented by Mr. Kroft before the Western Metals Congress in Oakland, Calif., late in March of this year. It collects together some tests at temperature on a number of alloys extensively studied by various agencies for the National Defense Research Council, and used during the war for critical portions of high-temperature equipment, notably gas turbines for aircraft engine superchargers and for main propulsion plants for highest speed airplanes. Future perfection of gas turbines and jet devices depends on further improvements in such ultrahigh-temperature alloys.

WARTIME DEVELOPMENTS have given great impetus to the so-called "superalloys" for application at temperatures from 1000 to 1500° F. Postwar developments in military aircraft and guided missiles are placing emphasis upon the best of these wartime alloys, particularly for application at ranges from 1400 to 1800° F. It is appropriate to discuss such alloys before a meeting of West Coast metallurgists. The gas turbine, as applied to the jet engine and the prop-jet engine, is of particular interest because of the great activity of the aircraft industry on the Coast in both the power plant and airframe design for jet planes. The applications of metals in the high temperature range just mentioned are primarily in highly stressed turbine blading and in high-temperature sheet for combustion chambers and exhaust systems.

This paper will be limited to the nickel-base and cobalt-base alloys manufactured by Haynes Stellite Co., and marketed under the trade names "Haynes Stellite", "Hastelloy" and "Multimet". Speaking generally, the "Stellite" alloys contain about 25% chromium and 6% of either tungsten or molybdenum, the balance being cobalt plus varying amounts of nickel up to 35% — thus being alloys based on chromium and cobalt. The "Hastelloy" alloys contain more than half nickel, up to one third molybdenum, and minor amounts of chromium, tungsten and iron — thus being alloys based primarily on nickel and molybdenum.

This paper will describe procedures for metallographic examination of the structures of these alloys and discuss the types of structures found. The effect of prolonged aging on microstructure, hardness, and physical characteristics will be illustrated, together with comments on desirable and undesirable types of aging for specific applications. Stress-rupture data in a temperature range of 1500 to 1800° F. will be shown for the various cobalt-base alloys to demonstrate the suitability of individual alloys for application to successively higher temperatures. Special emphasis will be given to these alloys in sheet form for applications where corrosion resistance at elevated temperatures and resistance to oxidation, carburization, and maintenance of high physical properties are of paramount importance.

Table I — Type Analyses of Chromium-Cobalt Alloys

	Cast Alloys			Forging Alloys		
Common name: N.D.R.C. reference: Haynes Stellite name:	Vitallium NR 10 Alloy No. 21	61 NR 60 Alloy No. 23	6059 NR 63 Alloy No. 27	422-19 NR 12 Alloy No. 30	X-40 Alloy No. 31	Low carbon N 155 NR 66 "Multimet" Alloy
Chromium	25 to 28	25 to 28	25 to 28	25 to 28	25 to 28	20 *(a)*
Molybdenum	5 to 6	—	5 to 6	5 to 6	—	3
Tungsten	—	5 to 6	—	—	7.5	2
Nickel	2	2	30 to 35	15	10 to 12	20
Cobalt	Balance	Balance	Balance	Balance	Balance	20
Carbon	0.20 to 0.30	0.40 to 0.50	0.40 to 0.50	0.40 to 0.50	0.40 to 0.50	0.10 to 0.20 *(b)*

(a) Plus 1% columbium and 0.14% nitrogen. *(b)* Also a high carbon variety is made (0.25 to 0.35%).

Metallographic Etchants

The various high-temperature alloys within the above classifications may be easily prepared for metallographic examination. The following electrolytic etchants are recommended to show their general structure:

1. 6% aqua regia for 3 sec., using 4 dry cells in series.

2. 5% hydrochloric acid for 3 sec., using 2 dry cells in series.

3. 5 to 10% chromic acid for 3 sec., using 2 dry cells in series.

Carbide constituents may be selectively stained by a very light preliminary electrolytic etch in a 2% solution of chromic acid for 1 sec. or less. The specimen is then dipped in an alkaline permanganate solution for approximately 7 sec. The alkaline permanganate solution is prepared just before use, by mixing equal parts of a 20% solution of potassium permanganate and an 8% solution of sodium hydroxide.

The recommended macro-etch for these high-temperature alloys is a solution of hydrochloric acid saturated with ferric chloride to which 5% by volume of concentrated nitric acid is added at the time of immersion. After etching, the specimen is dipped in 1:1 hydrochloric acid solution, rinsed, and dried. This etching reagent is used at 70° F.

Allotropic Forms of Cobalt

The crystallography of the cobalt-base alloys listed in Table I is far from simple, and considerable study has been made, especially of the structures found in Stellite* No. 21 (Vitallium). Cobalt metal exists in two lattice structures, one is face-centered cubic, and the other close-packed hexagonal. Although there is no known metallographic difference they may be distinguished by their X-ray diffraction patterns. Figure 1 shows the results of such studies on five alloys tested under four conditions: *(a)* As cast; *(b)* annealed at 2125° F.; *(c)* aged for 50 hr. at 1475° F.; *(d)* aged for 100 hr. at 1475° F. Standard patterns for the cubic and hexagonal forms of cobalt are also shown for the purpose of comparison at top and bottom of the chart. The vertical heights of the

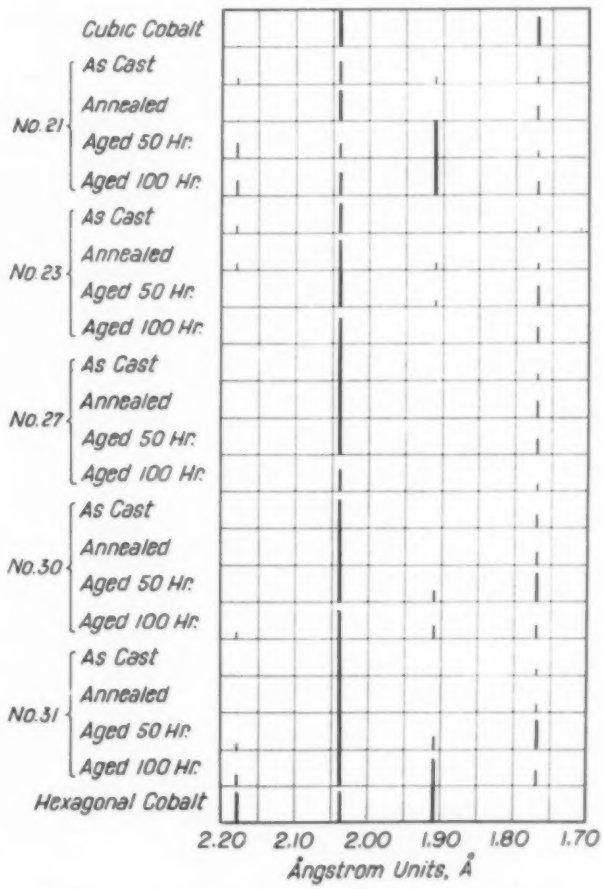


Fig. 1 — Intensity of Principal X-Ray Diffraction Lines of Cubic and of Hexagonal Cobalt in Pattern From Five Cobalt-Base Alloys, Each in Four Conditions

*When the reader sees such shortened forms as "Stellite No. 21", or even "No. 21", he should translate it into the correct legal designation: "Haynes Stellite Alloy No. 21".

lines and their widths are a measure of the intensity of the lines on the respective diffraction patterns. It may be noted that the principal line of cubic cobalt at 2.04 Å coincides with a strong line of the hexagonal form, so that the line at 1.77 Å must be used for establishing the presence of the cubic form. The strongest line of the hexagonal form is at 1.91 Å, and the strength of that line is a measure of the amount of hexagonal cobalt present in any sample.

From Fig. 1 it will be seen that No. 21 alloy (25 Cr, 6 Mo, 2 Ni, 65 Co) contains some of the close-packed hexagonal structure in the as-cast condition, but it is completely changed to the cubic structure by annealing. Upon aging, however, the hexagonal form becomes the major constituent. In both the as-cast and annealed conditions, No. 23 alloy (same as No. 21, except tungsten replaces molybdenum) contains a small amount of the hexagonal form. Upon aging, the hexagonal form disappears completely. Alloy No. 27 (25 Cr, 5 Mo, 35 Ni, 35 Co) shows only the cubic structure in all conditions. Alloy 30 (25 Cr, 5 Mo, 15 Ni, 60 Co) and No. 31 (25 Cr, 7.5 W, 10 Ni, 55 Co) shows only the cubic form present as-cast and as-annealed. After aging some hexagonal structure is present, but the cubic form is the major constituent.

For cobalt metal, the cubic form is stable above 750° F. and below 1850° F., while the hexagonal form is stable below 750° F. and above 1850° F. The effect of the addition of the alloying elements chromium, molybdenum, and tungsten is to raise the lower transition point; iron and nickel depress it.

It is not necessary to heat treat or pre-age these high-temperature alloys based on cobalt or nickel since they have excellent elevated temperature properties as-cast which are maintained and supplemented by aging in service in the range from 1300 to 2000° F. To illustrate the effect of prolonged aging on microstructure and hardness, samples of the various alloys were aged at 1475° F. for 5, 25, 50, 100, 500 and 1000 hr. The data sheet, page 400-B, shows the structures and hardness obtained on the five "Haynes Stellite" alloys as-cast and after aging 5, 50, and 500 hr.

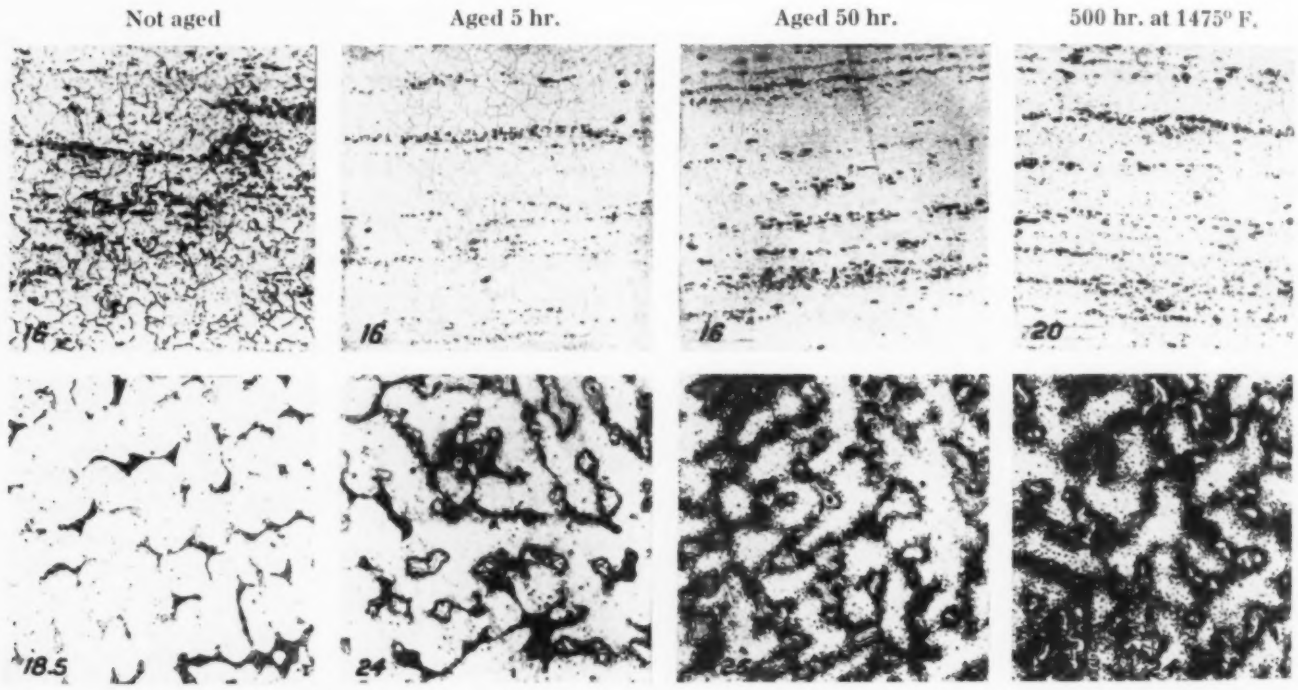


Fig. 2 — Microstructure of Multimet, Aged up to 500 Hr. at 1475° F. 250 ×. Top row, low-carbon wrought alloy as annealed at 2200° F. and as-aged; bottom row, medium-carbon investment casting, as-cast, and as-aged. Hardness measured on Rockwell C-scale

The top line shows the microstructures of alloy No. 21 (Vitallium), as-cast and after aging. The as-cast structure shows the cobalt-rich solid solution matrix with carbide islands well distributed. It also shows the dark eutectoid areas (Cr_4C and cobalt-rich solid solution) close to and along the grain boundaries. A much larger percentage of these eutectoid areas which are lamellar in their nature may be produced by very slow cooling from 2200° F. This eutectoid does not normally occur in precision investment castings of these alloys

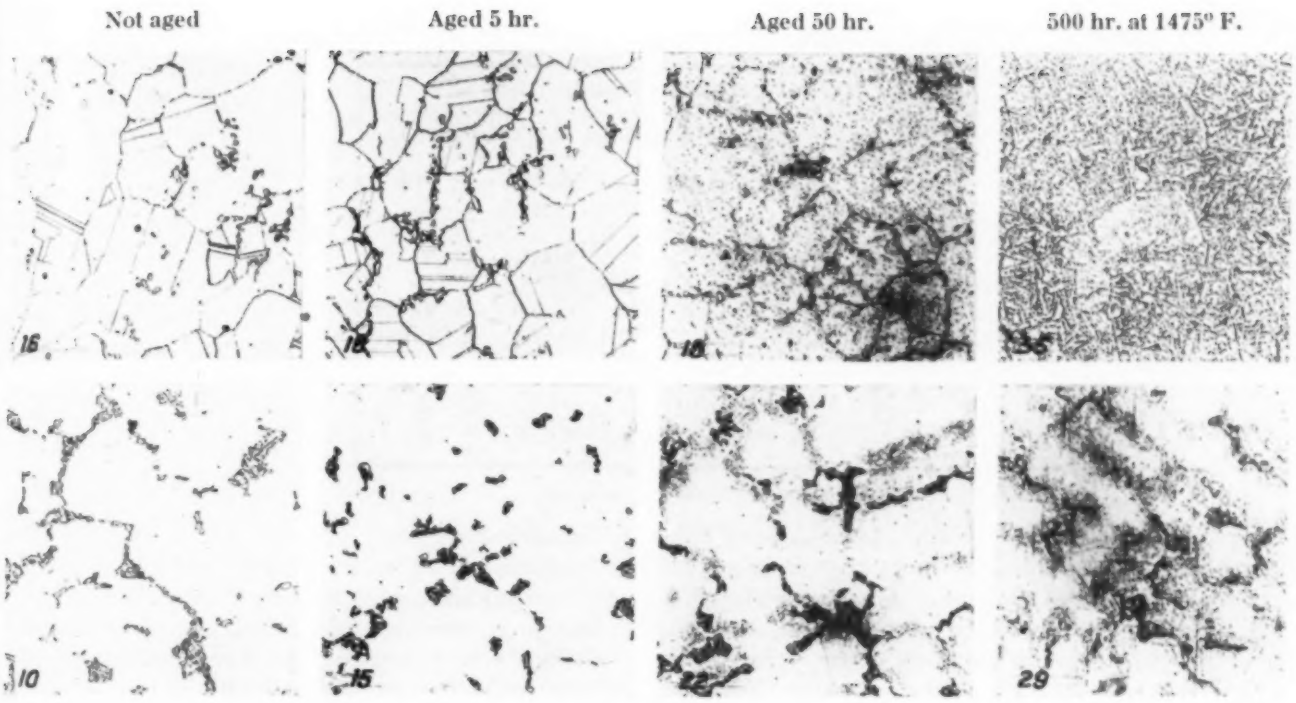


Fig. 3 — Hastelloy B, Wrought (Top Line) and Investment Cast. 250 ×

except slightly in No. 30. It will be noted that considerable aging of alloy No. 21 has occurred in 5 hr., but that this alloy ages progressively is evidenced by the increases in hardness up to 500 hr. It will later be shown that the increase in hardness between 500 and 1000 hr. is very minor.

The second row of micrographs in the Data Sheet shows the microstructures of Stellite No. 23 (otherwise known as 61 or NR60 — see Table I). As before the views are as-cast and following aging. This alloy is similar in composition to alloy No. 21 with the exception that the carbon range is

Fig. 4 — Hastelloy C, Wrought (Top Line) and Investment Cast. 250 ×

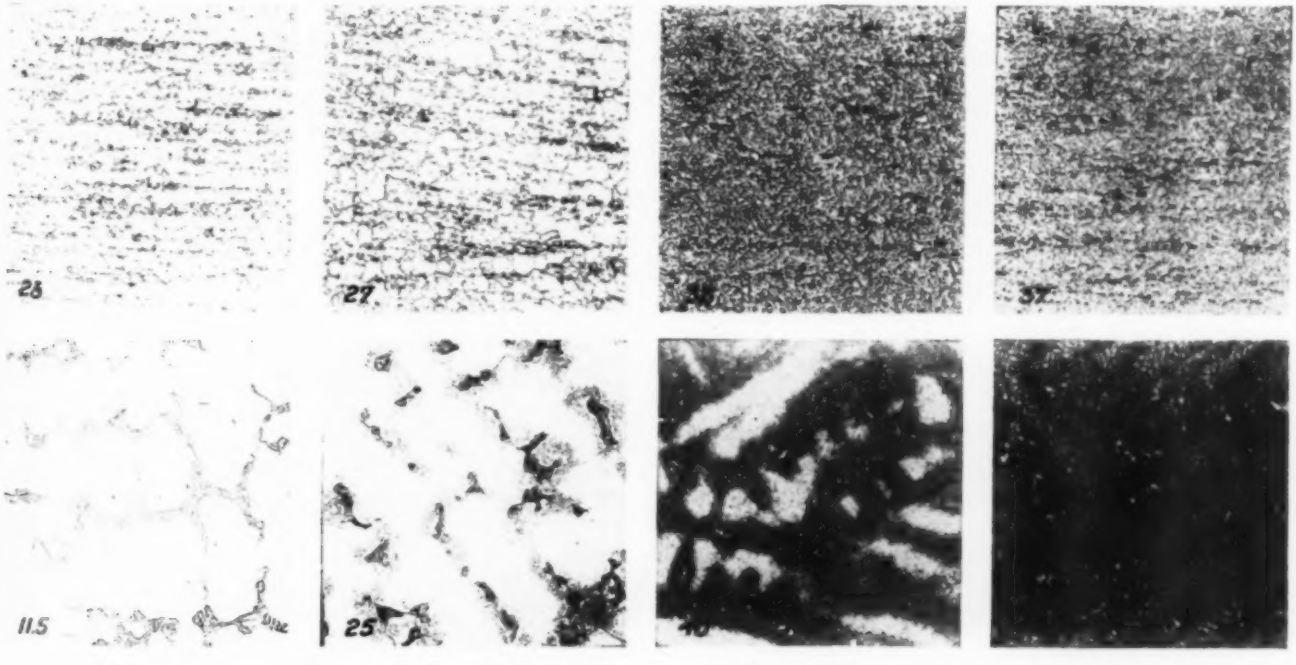


Table II — Hardness of Alloys After Aging at 1475° F.

Alloy	As-Cast or Wrought	Aging Period					
		5 Hr.	25 Hr.	50 Hr.	100 Hr.	500 Hr.	1000 Hr.
No. 21, cast	30	38	38	40.5	41	47.5	48.5
No. 23, cast	32	39.5	42	42	42	42.5	43
No. 27, cast	16.5	31	31.5	31.5	31.5	31.5	31.5
No. 30, cast	27	36.5	36.5	37	37.5	38.5	38
No. 31, cast	28	39.5	40.5	42.5	42.5	42.5	43
Multimet, cast	18.5	24	24.5	25	25	24	24
wrought	16	16	16	16	16	20	20
Hastelloy B, cast	10	15	18.5	22	27.5	29	34
wrought	16	16	16	18	29	35	35
Hastelloy C, cast	11.5	25	37.5	40	41	40	39
wrought	23	27	34	38	38	37	35

higher (0.40 to 0.50), and tungsten has been substituted for molybdenum. Note that this as-cast structure is void of the eutectoid seen in alloy No. 21. Almost the maximum aging based on hardness has been brought about by 50-hr. aging. The precipitation visible after 5 hr. at 1475° F. around the carbides is agglomerated at the end of 50 hr. with slight general precipitation throughout the grains themselves. The precipitation has agglomerated further around the carbides and grain boundaries after 500 hr. at 1475° F., with much more general precipitation throughout, but with very little change in hardness.

The composition of alloy No. 27 (6059 or NR63) is similar to that of alloy No. 21 with the exception that the carbon content is 0.40 to 0.50% and half of the cobalt has been replaced with nickel. As in alloy No. 23, the as-cast structure — shown at the left end of the central line of micros in the Data Sheet — is void of the eutectoid found in alloy No. 21. Alloy No. 27 is the softest of this group of cobalt alloys, and is the most readily machinable. Maximum age hardening has occurred in 5 hr. and progressive visible precipitation has occurred, extending into the grains in regions near the carbide constituent as the aging time has increased.

Alloy No. 30 (otherwise known as 422-19 or NR12) is similar in composition to alloy No. 27 with the exception that it contains only 15% nickel. Microstructures are assembled in the next-to-bottom row on page 400-B. The eutectoid is present in the as-cast structure but appears to be broken up after aging for 50 hr. at 1475° F. (Some evidence of this is shown after 5 hr.) Maximum age hardening is approached after 5 hr., with progressive visible precipitation occurring as the time at aging temperature lengthens to 50 hr. and beyond.

Alloy No. 31 (sometimes called X-40) is shown in the bottom line of micrographs in the Data Sheet. It is similar to alloy No. 23 in composition with the exception that it contains 7.5% tungsten and 10% nickel. The aging characteristics of this alloy are similar to those of No. 23.

Figure 2 (page 396) shows the microstructures of wrought Multimet alloy (otherwise called N155 or NR66) of low carbon (0.20% max.) in the top row, and precision investment cast alloy of medium carbon content (0.30 to 0.40%) in the bottom row. It is interesting to compare the aging characteristics of these two materials. The medium-carbon cast material ages to a

Table III — Short-Time Tensile Tests of Precision Cast Specimens
(Ultimate strength in roman numbers; *yield strength in italic numbers*)

Alloy	70° F.	1000	1200	1350	1500	1600	1700	1800
21, as-cast	101,500	69,000	74,500				42,000	33,300
	82,000	*39,000*	*38,000*					
Aged		86,000	90,000	78,000	60,000	42,000		32,500
		74,700	*71,500*	*63,400*	*49,000*		*33,000*	
23, as-cast	105,500	77,300	83,000				37,000	33,000
	58,500	*41,000*	*40,700*					
Aged				79,000		46,000	44,000	34,000
		72,700	*74,800*	*65,500*	*41,000*		*33,000*	
27, as-cast	82,500	50,300	50,000			43,000		34,000
	47,000	*37,000*	*35,000*					
Aged				66,300		41,500	45,700	34,000
				50,500	*38,000*		*31,000*	
30, as-cast	98,300	63,000	60,000				45,000	36,700
	55,000	*42,000*	*38,000*					
Aged				77,700	64,500★	49,200	47,000	38,500
				63,700	*46,200*		*35,800*	
31, as-cast	101,000	80,500	77,000					
	74,000	*50,200*	*37,500*					
Aged				76,000		49,000		
				53,300	*44,700*		*37,000*	

★At 1400° F.

greater extent than wrought alloy, low in carbon, but to a much less extent than Hastelloy alloys B and C (Fig. 3 and 4, page 397). The low-carbon wrought material ages* the least of any of the high-temperature alloys. Its original hardness is low (C-16) and only after exposure for 500 hr. at 1475° F. does aging to any extent occur; after 1000 hr. the hardness remains at C-20. Note also the fine grain of the wrought structure, as compared with the grain size of the various cast alloys.

Figure 3 shows the microstructure of Hastelloy B. The top row represents wrought specimens, as-annealed at 2200° F. and as-aged at 1475° F. for 5 to 500 hr. The bottom row shows conditions for precision investment castings. The carbide phase is believed to be of the M_6C type. As-cast, this alloy ages progressively to 1000 hr.; Also that alloys No. 27 and 30 reach approximate maximum hardness after exposure for 5 hr. and alloys No. 23 and 31 after 50 hr. at the aging temperature. Cast Multimet alloy, medium carbon, also reaches maximum aging in 5 hr. and ages the least of any of the cast materials.

Of the three alloys tested in the form of wrought bars and precision investment castings, it is only after exposure for 500 hr. at 1475° F. that any appreciable aging occurs in wrought low-carbon Multimet. Hastelloy B, cast and wrought, ages progressively up to 1000 hr. Alloy C, cast and wrought, ages to a maximum hardness in 100 hr., after which hardness decreases.

Alloys with excessive aging characteristics should be avoided, particularly those alloys in which aging and overaging (subsequent softening)

Table IV — Strength and Elongation of Sheet Material Under 0.040 In. Thick*
(Elongation, % in 2 in., shown in parentheses)

Alloy	70° C.	1200	1350	1500	1650	1800
No. 21	172,000 (20)	102,000 (16)		55,000 (8)	30,000 (10)	21,000 (14.5)
No. 23	194,000 (17.5)	153,000 (11.5)		82,000 (19.5)		38,000 (24)
No. 27	134,000 (15.5)	85,000 (17)			33,000 (2)	24,000 (17.5)
No. 30	150,000 (7)	101,000 (8)		55,000 (12)		22,000 (15.5)
No. 31	184,000 (31)	147,000 (14)		95,000 (11)		44,000 (13)
Multimet	116,000 (40)	54,000 (6.5)		35,000 (15.5)		17,000 (11.5)
Hastelloy C	126,000 (37)	76,000 (15)	61,000 (9)	46,000 (9)	30,000 (10)	19,000 (13)

*Room temperature tests on sheet specimens ½ in. wide by 9 in. long; elevated temperature test specimens were ½ in. wide by 7 in. long.

as-wrought, maximum hardness is obtained after aging for 500 hr. (see Table II, page 398).

Similarly, Fig. 4 (page 397) shows the microstructures of Hastelloy C in the wrought and cast conditions before and after aging. (Wrought specimens were annealed at 2200° F.) As-rolled and annealed structures show spheroidal particles imbedded in the matrix of nickel-rich solid solution. Material at the grain boundaries has been partially dissolved by the annealing treatment at 2200° F. Investment castings age progressively up to 50 hr. after which the hardness levels off, although the precipitation appears to be more widely dispersed at 500 hr. As-wrought, maximum hardness is obtained after 50 hr., and the hardness drops off slightly at 500 and 1000 hr.

Aging Characteristics

Changes in hardness with aging time at 1475° F. are summarized in Table II. This shows that alloy No. 27 is the softest of the cobalt-base alloy series and that alloy No. 21 ages progressively and to a higher hardness than the other materials. occur at relatively low temperatures. Such excessive aging would bring about a consequent loss of desirable properties not only from exposure to slightly higher temperatures than those intended, but also at short periods of time.

Short-Time Tensile Tests

Variation in ultimate tensile and yield strength at temperatures from room to 1800° F. for the cobalt-base high-temperature alloys both as-cast and after aging at 1350° F. is shown in Table III. All of these results were obtained by standard short-time tensile tests on precision investment cast test specimens, ¼ in. diameter. Short-time strength in the temperature range of 1000 to 1200° F. is considerably increased by aging; however, the ductility (elongation in 2 in.) is greatly reduced. The greatest variation in tensile strength of the alloys is shown at 1000 to 1200° F. At these temperatures, alloys No. 23 and

*The term "ages" refers to changes in hardness and microstructure after holding at temperature — 1475° F. in the experiments described in this paper.

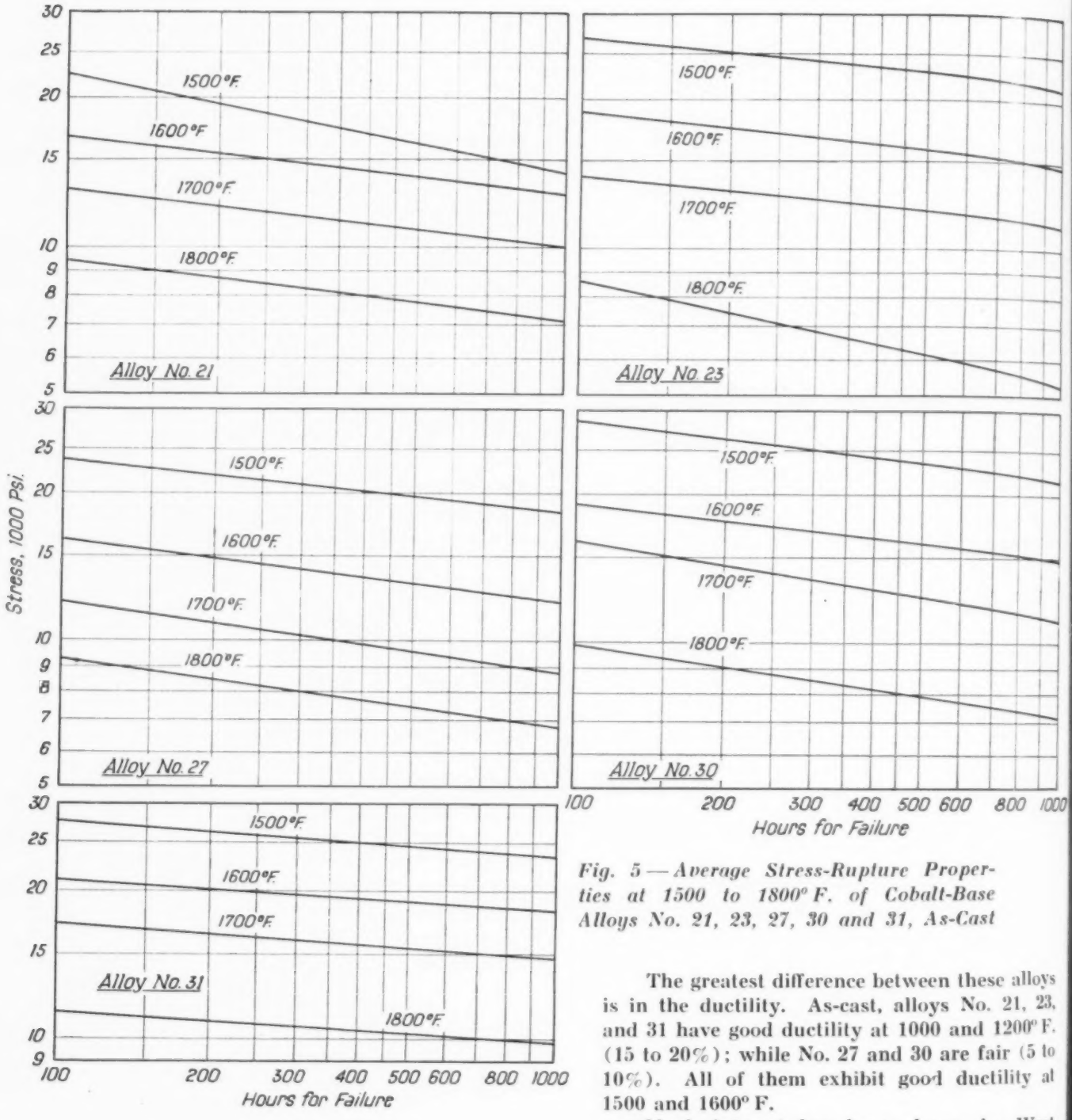


Fig. 5 — Average Stress-Rupture Properties at 1500 to 1800° F. of Cobalt-Base Alloys No. 21, 23, 27, 30 and 31, As-Cast

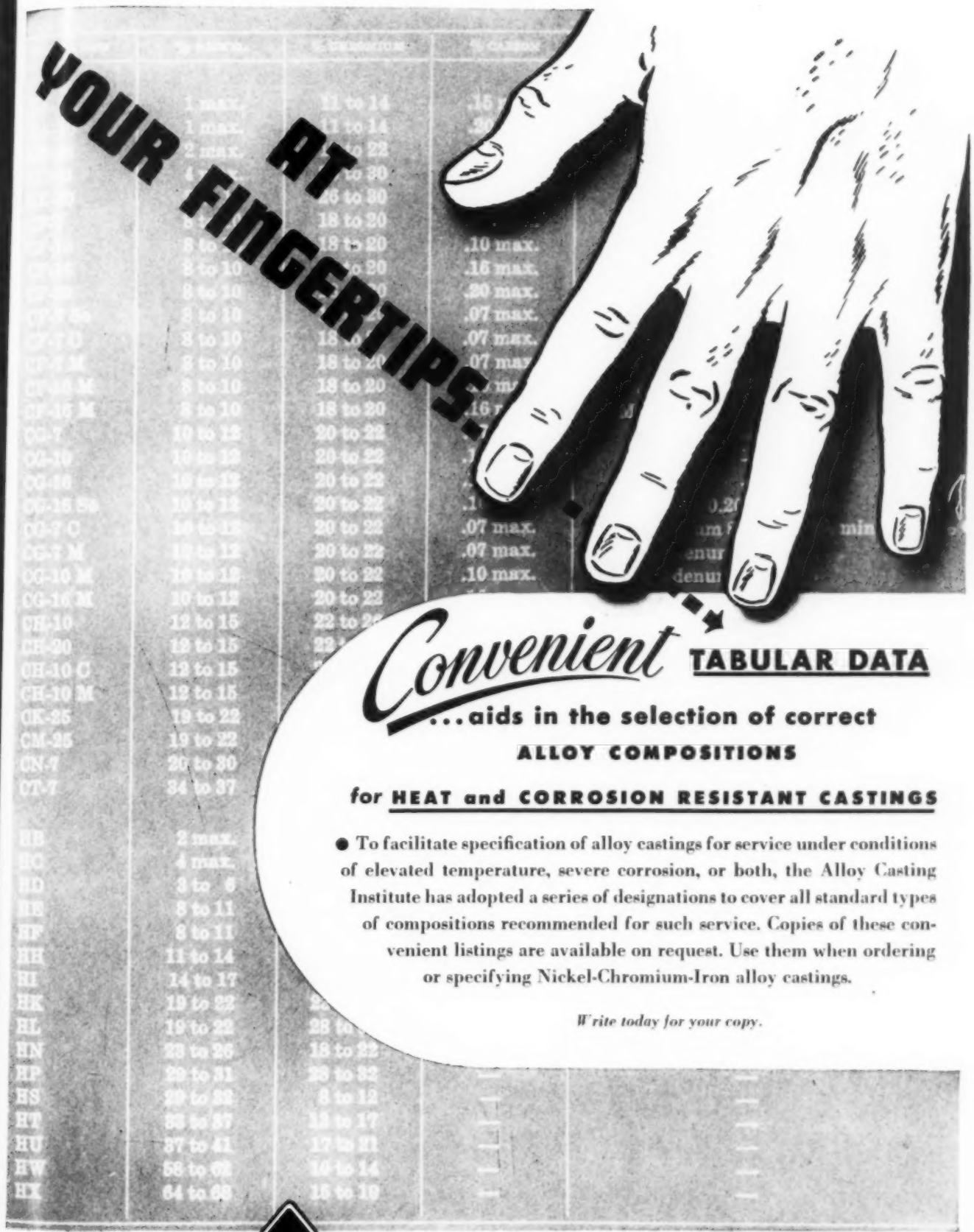
31 show the highest tensile strengths and No. 27 the lowest of the alloys tested in the as-cast condition. The differences in tensile strengths at 1350, 1500 and 1600° F. are not large; at these temperatures alloy No. 27 has the lowest strength and the others are slightly stronger.

The beneficial effect of aging on the yield strength of these alloys is also shown by the results in Table III to be quite marked; the values for alloys No. 21 and 23 are almost doubled at 1000 and 1200° F.

The greatest difference between these alloys is in the ductility. As-cast, alloys No. 21, 23, and 31 have good ductility at 1000 and 1200° F. (15 to 20%); while No. 27 and 30 are fair (5 to 10%). All of them exhibit good ductility at 1500 and 1600° F.

Much interest has been shown by West Coast metallurgists in these alloys in sheet form for combustion chambers and exhaust systems. The short-time strength and elongation measurements obtained on specimens under 0.040 in. thick are shown in Table IV, page 399.

The cobalt-base materials show much higher strength than nickel-base alloy C and Multimet. Alloys No. 23 and 31 show exceptionally high strength at elevated temperatures, with alloys No. 21, 30, and 27 following in the order listed. However, the room-temperature elongations for these



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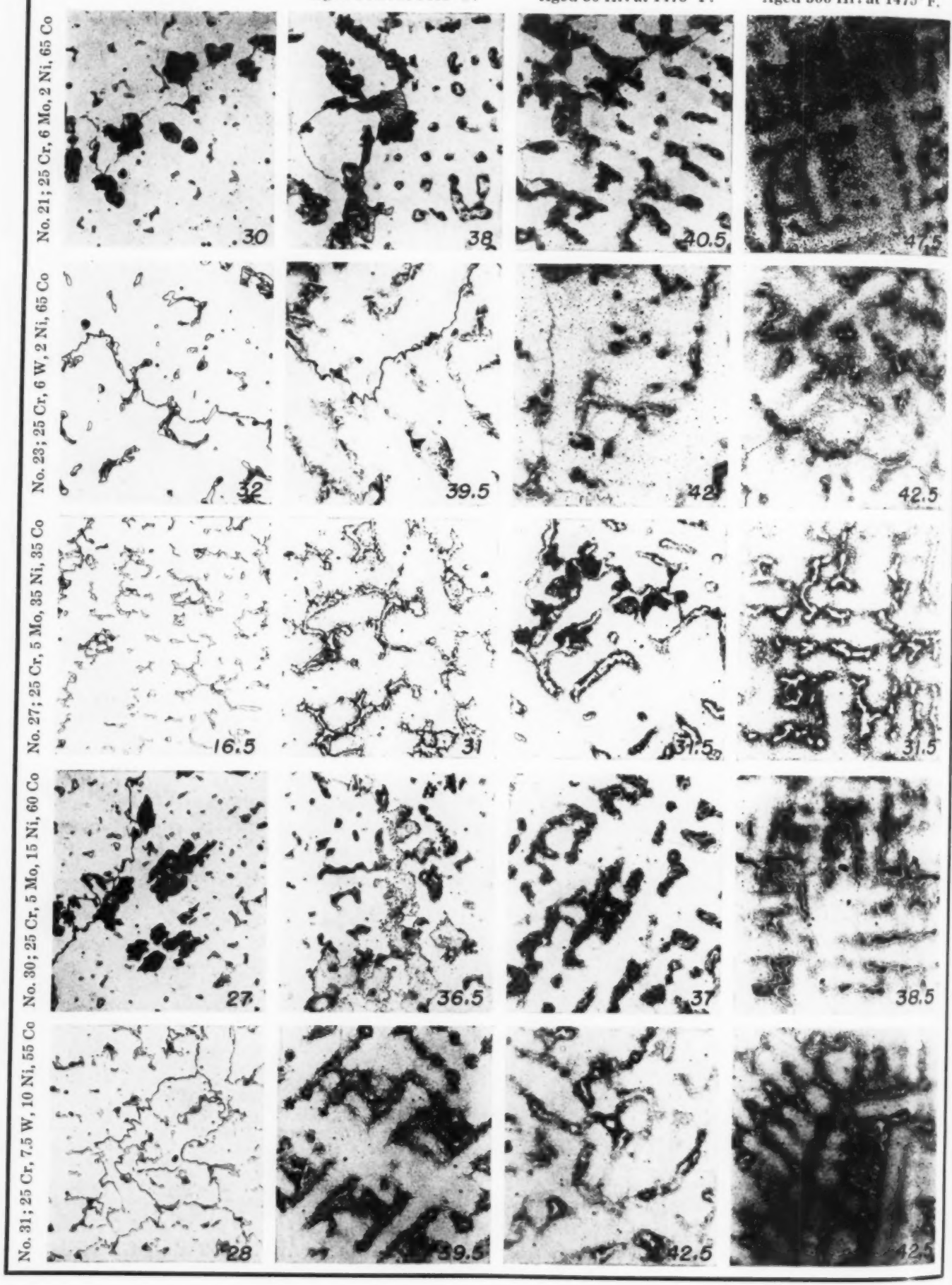
As-Cast and Aged Structures of Cr-Co Alloys

(Haynes Stellites; Magnification 200 ×; Rockwell C-Scale Hardness)



cobalt-base alloys are considerably less than those of the other two, and consequently create more of a fabrication problem. The 31% value shown for alloy No. 31 at room temperature is the result of only a few tests, but recent check tests on specimens annealed at 2200° F. showed an average elongation value of 29%, an ultimate strength of 176,000 psi., and a yield strength of 85,000. This high room-temperature elongation makes alloy No. 31 sheet more attractive for forming operations than the other cobalt-base alloys in sheet form, particularly as it is the strongest alloy above 1400° F. Stress-rupture and elongation tests are being conducted on these alloys in sheet form at the present time.

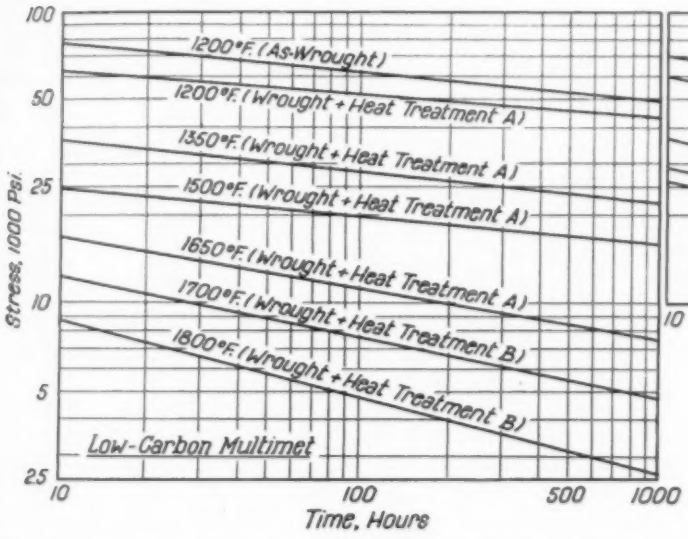


Fig. 6 — Stress-Rupture Data for Wrought Low-Carbon Multimet. Heat treatment A: Water quenched after 1 hr. at 2280° F., air-cooled after 4 hr. at 1500° F. Heat treatment B: Air-cooled after 30 min. at 2280° F.

Stress-Rupture Tests

Figures 5 to 7 compare the stress-rupture properties of these alloys at 1200 to 1800° F. At 1500° F. alloys No. 23, 30, and 31 show rupture in 100 hr. at stresses between 27,000 and 29,000 psi. and rupture in 1000 hr. at stresses between 21,000 and 24,000 psi. (Fig. 5). Alloys No. 21 and 27 have lower stress-rupture properties at this temperature than No. 23, 30, and 31. At 1600° F. No. 31 exhibits the best properties, rupturing in 100 hr. at 21,000 psi. and in 1000 hr. at 18,000 psi., while alloy No. 27 shows the lowest stress-rupture properties (a 100-hr. rupture strength of 16,000 psi. and a 1000-hr. rupture strength of 13,000 psi.).

At 1700° F. the stress-rupture properties of alloy No. 30 drop off more rapidly than the other alloys, as may be seen by comparing the slopes of the lines. At 1800° F. the superiority of alloy No. 31 may readily be seen. Its stress-rupture strength is 50% greater than alloy No. 30, the next best alloy.

At 2000° F. — not shown in Fig. 5 — alloy No. 21 ruptured in 10 hr. at 4200 psi., alloy No. 30 in 10 hr. at 5500 psi., and in 100 hr. at 3000 psi.; alloy No. 31 ruptured in 10 hr. at 6300 psi. and in 100 hr. at 4000 psi.

Figure 6 shows the stress-rupture properties of low-carbon Multimet. It will be noted that it maintains its strength much better than Hastelloy B, as is evidenced by comparing the slope of the stress-rupture curves for these two materials in Fig. 6 and 7.

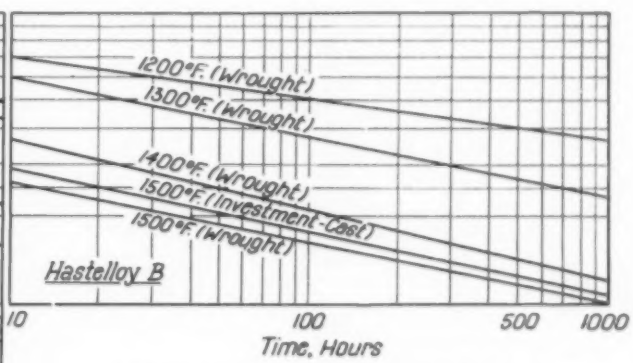


Fig. 7 — Average Stress-Rupture Data for Hastelloy Alloy B

Similarly, Fig. 7 shows stress-rupture properties of Hastelloy Alloy B in the temperature range of 1200 to 1500° F. Properties of the alloy, in the form of precision investment castings, are somewhat superior to those obtained when in the wrought condition. This alloy oxidizes noticeably at temperatures over 1400° F.; consequently, applications at these higher temperatures must be made with the oxidation factor in mind.

No stress-rupture data are available on the cobalt-base alloys in sheet form, but preliminary stress elongation tests on Hastelloy C showed a total elongation of 0.3 to 0.4% for a period of 500 hr. at 1200° F. under a stress of 15,000 psi. Sheet Multimet alloy, tested at the same temperature and stress, showed a total elongation of only 0.258% in 739 hr.

Carburization

Some difficulties encountered with exhaust manifolds and combustion ducts have been ascribed to carburization. Consequently, carburization tests have been conducted on alloys No. 21, 30, 31,

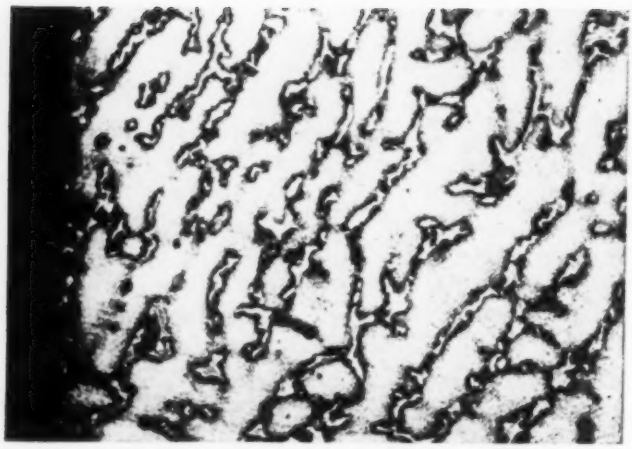


Fig. 8a — Alloy No. 31 (Cast), Heated 100 Hr. at 1650° F. in Commercial Carburizer. 100 ×

as precision investment cast, and Hastelloys B and C, and low-carbon Multimet in sheet form. For comparative purposes, samples of stainless steel, Types 310, 321, and 347, were also included. All were carburized for 100 hr. at 1650° F. in commercial "Carbo" compound, changed every 25 hr.

Alloy 31 showed no definite case. Hastelloy C showed a case of 0.008 in. and Multimet 0.012 in. The stainless steels, Types 321 and 347, showed cases of 0.030 in. It was apparent, after examining all of the test specimens, that when using a solid carburizer such as "Carbo" and alloys resistant to carburization or diffusion of carbon, both carburization and decarburization influences were active — at least at 1650° F. R. V. Hilkert of Solar Aircraft has pointed out in his report on "Microstructure of Carburized Alloys" that a similar behavior was observed in certain of his specimens.

Consequently, two additional check carburizing tests were made. The first was for 25 hr. at 1650° F., renewing the "Carbo" at the end of 12-hr. exposure. The second test was run at 1740° F. for 50 hr., substituting fresh "Carbo" three times during the run. These check tests confirmed the relatively high resistance of alloys No. 21, 30, 31 and Hastelloy C to carburization, and indicated that Multimet approximates the resistance of the last mentioned. However, case depths were again irregular and, apparently, some decarburization as well as carburization had taken place. Gas carburizing may be necessary to control the carburizing atmosphere accurately (and particularly the $CO : CO_2$ ratio) and would also more nearly duplicate the conditions encountered in service.

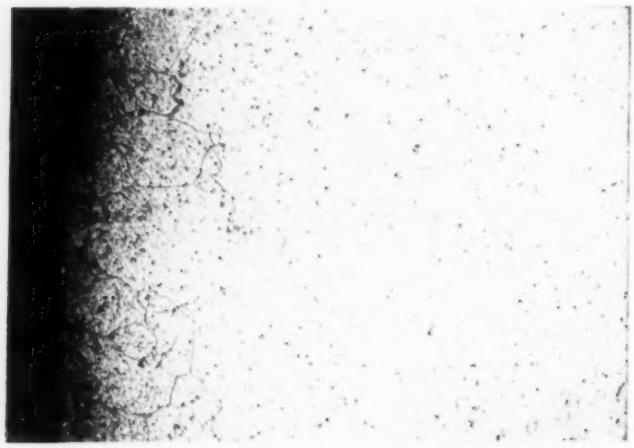


Fig. 8c — Multimet Sheet, Carburized 100 Hr.

A Concluding Note on Method of Testing

At the present time, because of the wide variety of applications for which these ultrahigh-temperature alloys are now being considered,

Fig. 8b — Hastelloy C Sheet Heated 100 Hr. at 1650° F. in Commercial Carburizer. 100 ×

there is no general agreement as to the type of physical tests on which the development of improved alloys or the purchase of developed alloys can be based. Many improvements can doubtless be made on the methods used for testing them, and extensive work is now being carried out on sheet material by West Coast companies. The proper appraisal of the properties of these alloys, such as fatigue, stress-rupture, and creep, coupled with formability and maintenance of strength and ductility for short periods of local or general overheating, presents a very difficult problem.

This problem must be met by the metallurgist who is faced with the responsibility of choosing the alloys to be used for specific applications, and also by the metallurgist endeavoring to develop improved alloys for service at extremely high temperatures.

Basic Ports and Roofs in European Openhearth Furnaces

By Pierre Bettembourg*
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Pompey Steel Works
Meurthe-et-Moselle, France

Use of basic brick for openhearth furnace roofs in European steel mills was preceded by much experience with their performance in linings of gas ports. When their spalling tendency is counteracted by appropriate cleaning and repair, the results are quite satisfactory. Self-supporting, insulated roofs of 15-ft. span (45-ton furnaces) have lives up to 1200 heats. Longer span roofs require some external support in the form of suspenders from overhead beams. European experience is apparently limited to gas-fired furnaces no larger than 85-ton capacity.

THE OPENHEARTH furnace has been developed along different lines in Europe and France from those in England and America. For one thing, it makes but a fraction of the basic bessemer production. The latter makes almost all the common steels. This has resulted in the neglect of the openhearths, which are frequently relegated to the remelting of converter scrap. Furnaces are old and of small capacity, averaging about 40 metric tons (about 45 short tons).

Engineers have therefore had to get the most out of their mediocre installations — all the more so, since for some years before the war the price of openhearth steel was no higher than that of basic bessemer, which led to a great demand. To increase production, the heat input to the furnace was increased, but this was limited by the performance of the refractory linings used at that time (silica for the roof, gas and air ports and front-wall; magnesia, chrome ore, or tar-dolomite mixes for the rear-wall).

Difficulties were encountered in the wear of the ports, especially in the partition between the gas and air flues — that is, the *langue* or "tongue". When furnaces were shut down for repairs, it was not unusual to find the tongue eaten back as much as 6 ft., with corresponding poor direction of the flame, erosion of the roof, and high fuel consumption.

On the other hand, protection of the ports by water-cooled blocks involves a prohibitive heat loss in these small-capacity furnaces. For these reasons, the first appearance of basic refractory brick in the furnace superstructure stirred up considerable interest among steelmakers in Central Europe and France. Here was a possible means of not only stepping up production by increasing heat input, but also of increasing the length of a campaign. Increased cost of the new brick would be accepted provided increased steel production could be obtained by stepping up hourly rate and by reducing downtime for repairs.

Ordinary magnesia brick, long used in the construction of furnace bottoms, cannot be put into the front-walls, ports, or roofs, because of their extremely poor resistance to temperature variations.

According to some manufacturers of chrome-magnesia and special magnesia refractories, these brick will withstand 50 cycles of heating and cool-

*Translated from the French by William M. Baldwin, Jr.

ing in an air jet from 1600° C. (2900° F.) without crumbling. However, just put them on the floor of an openhearth furnace port in full operation and it is found that none of the chrome-magnesia brick can survive. The best of them lose their corners; the others crack or completely disintegrate. The only commercial brick that resists this exposure, in my experience, is one having a very pure magnesia base (trade name "Magnesidon").

Whatever the results of the laboratory tests may be, it is a fact that ordinary magnesia brick as well as the rest of the chrome-magnesia brick of mediocre quality fail by spalling or by collapsing when built into the gas and air ports of an openhearth furnace, although chrome-magnesia brick of *good* quality are perfectly resistant when certain precautions that will be mentioned later are taken.

European Brick Available

European basic refractory brick available before 1939 could be classified into two types:

1. Brick made of purified magnesia (95% MgO). These are made from fused magnesia particles mixed with extremely fine dust of the same material, formed under high pressure and burned at very high temperatures. They are characterized by an excellent resistance to temperature changes and a better resistance to compression under load than ordinary magnesia brick. Examples are "Magnesidon" and "Radex B".

2. Chrome-magnesia brick are based on fritted magnesia and chrome ore (about 60% of the latter in "Radex E"). They are characterized by a poorer resistance to temperature change and compression under load than those described above but are considerably better than ordinary magnesia brick (85% MgO). Nevertheless, purified magnesia brick are not widely used, since (in large fuel ports especially) they do not perform as well as chrome-magnesia. During the war, the Germans developed a straight magnesia brick because of the acute shortage in chrome ore, but they were never comparable to the better grade prewar chrome-brick. Examples of this category are "Radex E" and "Lovinit III".

The present paper will therefore be confined to chrome-magnesia brick only, and specifically to "Radex E" which are the most widely used on the Continent.

Table I — Characteristics of European Refractory Brick

	Silica	Ordinary Magnesia	Radex E	Magnesidon
Nature	95% SiO_2	85% MgO	60% chrome ore	95% MgO
Specific gravity	1.6 to 1.9	2.80	2.95	2.7 to 2.8
Softening point (2 kg. per sq.cm. or 28.5 psi.)				
Start	1630° C. (2965° F.)	1500 to 1550° C. (2730 to 2820° F.)	1550 to 1600° C. (2820 to 2910° F.)	1600 to 1650° C. (2910 to 3000° F.)
End	1660° C. (3020° F.)	1600° C. (2910° F.)	1650 to 1700° C. (3000 to 3090° F.)	1680° C. (3055° F.)
Expansion from 0 to 1000° C. (32 to 1832° F.)	1.2 to 1.3%	1.2%	0.96%	1.23%
Conductivity				
at 100° C.		5.8		2.6
500		4.9		3.0
800			2.0	3.4
1000			1.0	3.1
1200	1.4 to 1.6		1.2	
Number of air quenches from 950° C. (1740° F.)	1	1	70 (?)	60

Properties of "Radex E" brick and those of other types are compared in Table I (taken from A. Heger, *Stahl und Eisen*, March 7, 1935). Even though the tests on "Radex E" are inferior to "Magnesidon" (purified magnesia), and the prewar chrome-magnesia brick was quite variable, in actual performance the basic refractory bricks were behaving in a consistent fashion. Apparently their behavior in burner ports and roofs cannot be predicted from laboratory tests.

It is the writer's opinion that the compressive strength and stability under temperature variations are complex quantities that involve the following elements: *(a)* Coefficient of expansion; *(b)* thermal conductivity and its temperature coefficient; *(c)* chemical stability with regard to gases and dust; *(d)* change of *(a)*, *(b)* and *(c)* caused by changes in chemical composition resulting from infiltration of gas and foreign material; *(e)* the ability of the brick to withstand compression during prolonged load at high temperature.

Because of these different factors, the compressive stresses in the lining in service can be quite different from those determined by preliminary calculation. The highest values are reached where the lining's composition has been modified to the point where the compressive strength is less than that measured in the laboratory. Under these conditions, the better refractories are those whose fundamental properties listed above are such that the *actual* compressive stresses approach the calculated and which remain plastic in the regions where the limiting stress is exceeded.

It would be fortunate if the test methods would approach the working conditions more closely. As long as this is not true, metallurgical engineers are obliged to depend on the brick suppliers and risk occasional failures. It is the part of wisdom to try an unknown refractory in the rear-walls or front-walls first, then in the burner ports, and finally in the roofs.

Characteristics of Ports and Roofs

The high specific gravity of basic brick (compared to silica) means a greater weight of roofs of ports and furnace. It is well to calculate the stresses, and this is done for three simple arches of silica brick (specific gravity 1.8) and of "Radex E" (specific gravity 2.9). Figure 1 is calculated on the basis that the load is from the weight of the brick only and that the resultant stress operates perpendicularly to the supporting surface — a condition that is theoretically obtainable by appropriate shimming, at least in large arches.

The horizontal component of the stress acting on the supporting skewback has also been determined. Stresses have been calculated for a span of 1 m. (39.4 in.). To obtain the stresses for other arches of corresponding rise, it is only necessary to multiply the figures thus calculated by the ratio of actual to computed span. The results will be a little too low for arches which support several courses of fill-in brick such as shown in the port design in Fig. 3, page 407.

The first ports made of basic brick were adapted to the characteristics of the new material. The difficulties which had to be overcome were as follows:

1. The softening point of chrome-magnesia brick is a little lower than the silica refractory; this instability is aggravated by the higher specific gravity and "creep" of the basic brick.

To compare the softening points of refractories it is convenient to refer to diagrams drawn by Daniel Petit in his article on "Methods of Calculation for Refractory Linings" (*Chaleur et Industry* for February and March, 1939). Two of his diagrams are consolidated in Fig. 2, and are curves for a typical silica brick and a chrome-magnesia brick. They indicate the maximum temperature and compressive stress at which deformation occurs.

Now for a port burner 30 in. wide, the maximum compressive stress in the case of an arch with 13.5% rise will be 1.9 psi. for silica brick and 3.1 psi. for "Radex E". According to Petit's diagram, this corresponds to 1710 and 1725° C. (3110 and 3135° F.) respectively. Since this is a temperature which would be reached only superficially in a port wall or arch, "Radex E" should be safe to use under the given circumstances.

It is easily possible, however, that the actual compressive stress is greater than calculated, since free expansion cannot occur within the mass of brickwork. If, for the sake of argument, it is assumed that the compressive stress in the port lining is twice that calculated, then it appears from the Petit chart that a 4-psi. compressive stress still corresponds to a temperature around 1700° C. (3090° F.) for silica, whereas a 6.25-psi. compressive stress corresponds to a temperature

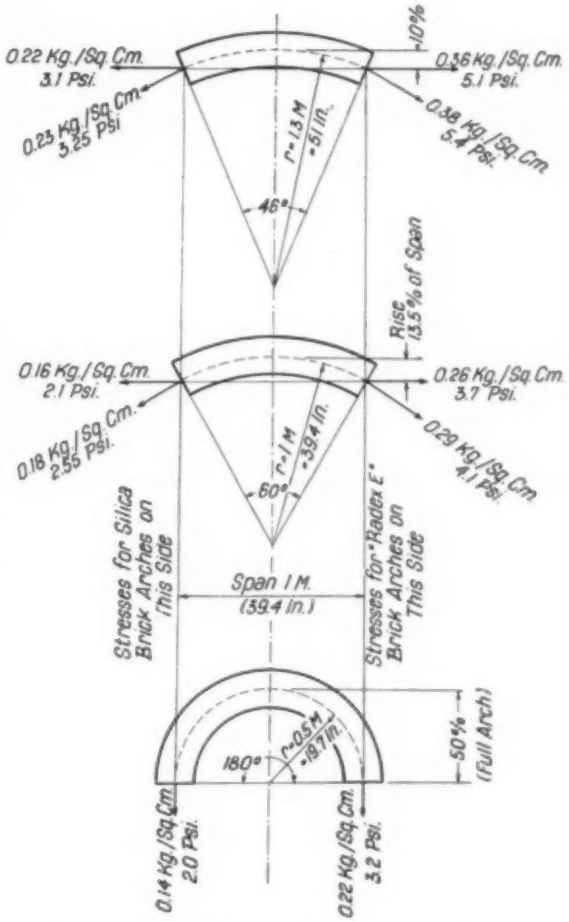


Fig. 1 — Compressive Stress at Ends and Thrust on Skewback for Various Arches of Silica and Basic Brick

of only 1630° C. (2965° F.) for the "Radex E" brick. It is obvious that the safety factor is lowered considerably in the basic refractory.

This difficulty is eliminated by constructing the ports with a full arch. The calculated compressive stress is only 2.4 psi. — or 5.0 psi. when doubled to account for expansion. This corresponds to a permissible temperature of 1680° C. (3060° F.) for "Radex E". The use of a full arch is of equal benefit with regard to creep.

Our design shows the gas port, tongue, and end-walls built of basic brick according to this principle. In spite of very long campaigns, the arch shows no appreciable shrinkage after 900 heats. Special attention is drawn to the ½-in. expansion joint between the basic and silica refractories.

2. Clogging the port is a common nuisance when it is made of basic refractory brick. It is caused in part by a slight spalling of the brick, and in part by basic dust which collects on the floor of the passage as the refractory is corroded. This rubble is prone to swell; if it is not cleaned out promptly the layer will rapidly attain a depth of 6 to 8 in., the fuel gas and products of combustion are obstructed in their flow, the temperature of the ports and the throat falls rapidly, and this results in a considerable increase in time for melting the charge.

All these drawbacks are remedied by vigorously scraping the burner floor. To be effective, this should be done at least once a day, after tapping, when the passage is hottest. The scraping tool should be a heavy bar about 2 in. in diameter, with a pointed crooked end; it should be worked like a ram by the furnace crew. Such scraping is absolutely necessary for successful operation of furnaces with basic refractory ports and end-walls.

The following additional measures must also be used:

The gas port should be floored with silica brick (either splits 1¼ in. thick or standard sizes) laid flatwise at least for a length of 3 ft., starting from the end of the tongue. The above-mentioned rubble deposit is then removed with ease. A silica floor, however, is efficacious only at the beginning of a run; since silica melts rapidly, it is necessary to replace it with chrome ore or magnesia.

Crushed silica brick may be scattered on the rubble to soften it before scraping the floor, especially if there are heavy deposits to clear out. Fluxing materials such as sodium carbonate or spar are not recommended, for they fuse too rapidly to have time to attack the deposit and they may flow down on the hearth where they can cause considerable damage.

In spite of these precautions, it is impossible to prevent some buildup on the port floor. Consequently, basic ports should be constructed with a cross section oversize by 20%. After about 600 heats, the floor of the port has been built up by 6 to 8 in., and it is then best to crack up the deposit while it is cold during a shutdown for roof repairs. After the same number of heats we have observed that about half the thickness of the lower course of arch brick has spalled off.

3. Chrome-magnesia brick will not fuse, even superficially, at the usual temperatures attained in an openhearth furnace; the basic refractory lining thus does not glaze into a coherent mass as does silica brick. The usual method of interleaving basic brick with strip steel can be used to "weld" the brick; on heating, the metal oxidizes and the iron oxide effectually seals the joint between the bricks.

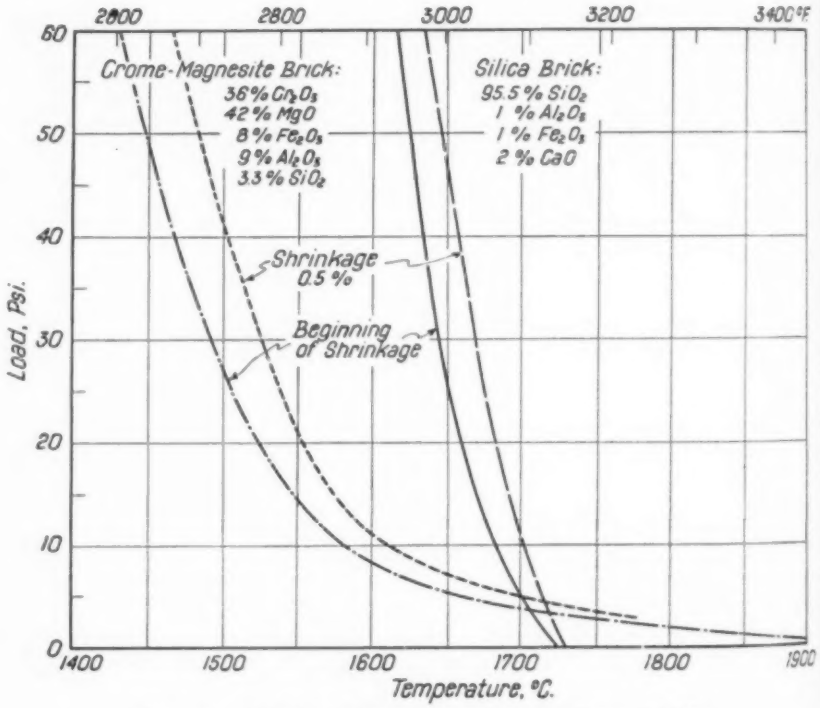


Fig. 2 — Petit's Diagram for Representative Silica and Chrome-Magnesite Refractory Brick

At the Pompey Steel Works we have given this method up, since gas escapes through these joints at the beginning of the heat, and the holes

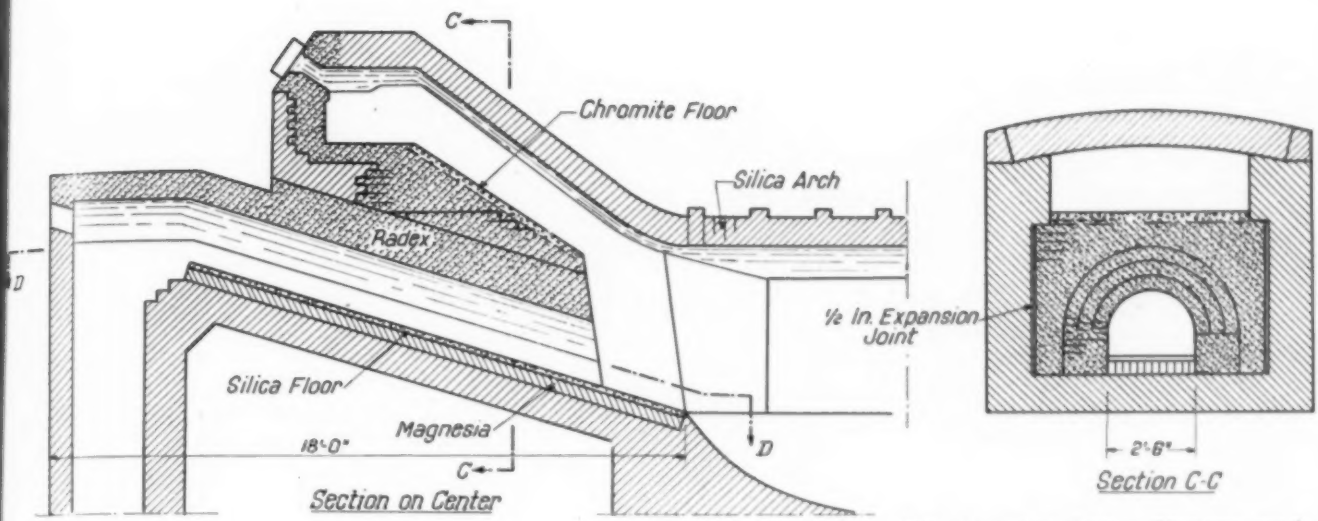
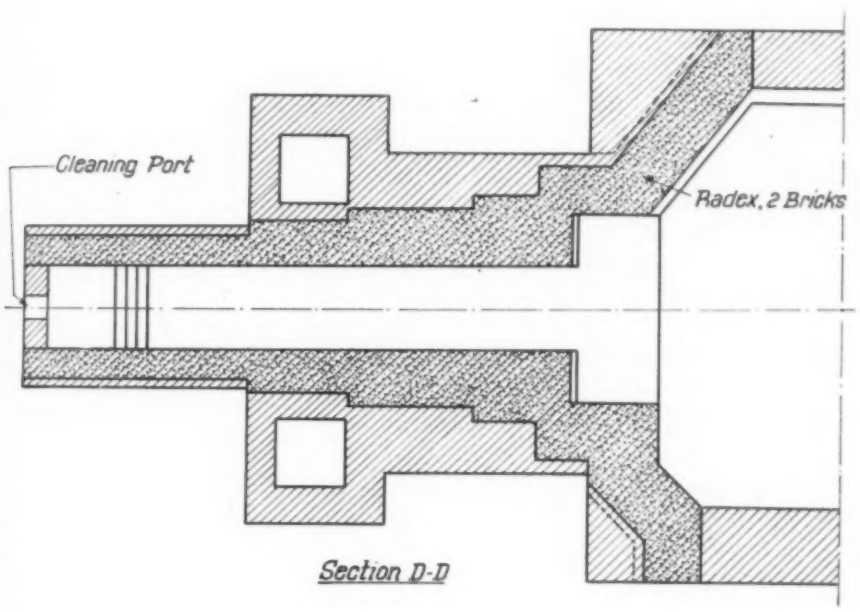


Fig. 3 — Gas Ports, Tongue and End-Walls Made of Chrome-Magnesia Brick in 45-Ton Furnace Heated With Producer Gas. Scale, $\frac{3}{16}$ in. = 1 ft.



thus created do not close, and are conducive to lining failures. We have adopted, instead, the procedure of filling the joints with a chrome-magnesia mortar mixed with sodium silicate, the thickness of the joint being about $\frac{1}{16}$ in.

In spite of the good results obtained with basic brick ports, attempts have been made to increase the length of a campaign by cooling them. It is not a question (as it is with silica refractory) of reducing the amount of fusion by placing a cooling baffle between the flame and the brick. Rather, it is a question of reducing the thickness of the masonry subjected to the high temperatures, with the thought in mind of limiting the softening of the brick and the depth of chemical attack by fumes and dust.

Such cooling is done by 1-in. pipes placed between the lower course of brick in the arch and the second course on the inside of the lining. The heat so absorbed is obviously much less than in the arrangement where cooling plates are exposed directly to the flame.

Construction of Basic Roofs

Construction of a basic roof is a very delicate job, even when brick of unquestioned quality are used. The least defect in design, construction or supervision will lead to failure.

These difficulties can best be understood by calculating the probable compression in roof brick. For an arch with a 15-ft. span (45-ton furnace) with a rise of 10%, the compression will be 4.5 times the value shown at top left of Fig. 1, or 24.3 psi.; if the rise is 13.5%, the compressive stress becomes 18.5 psi.

Reference to the line for chrome-magnesite brick in the Petit diagram of Fig. 2 shows that the temperatures at which deformations will begin for these pressures will lie in the interval of 1500 to 1535° C. (2725 to 2790° F.), which is obviously less than the working temperature of the under surface of the arch. Even if it is assumed that the brick studied by Petit was of mediocre quality, and that the temperature corresponding to a good quality "Radex E" brick is some 30 to 50° C. higher, it is impossible to prevent a certain thickness of the roof from exceeding the permissible limit. This is not serious if this thickness is

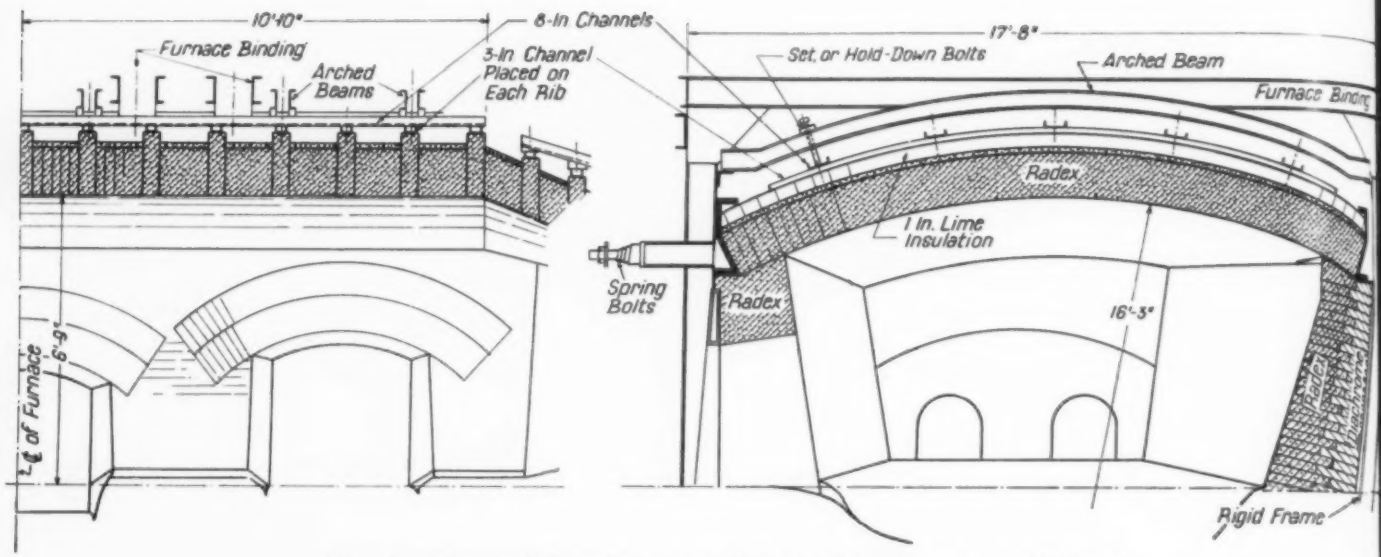


Fig. 4 — General Drawing of Self-Supporting Roof on All-Basic Furnace, 45-Ton Capacity, Lasting 1100 to 1200 Heats. Steel corseting is to prevent local rise in brickwork. Scale, ¼ in. = 1 ft.

slight and if the material is plastic. It is only necessary that the remaining thickness of arch be sufficient to resist the compression — even after partial wear.

This involves the desirability of insulating the roof. European steelmakers commonly insulate basic roofs by a 1-in. layer of lime to take best advantage of the high heat resistance and to diminish radiation losses due to the high thermal conductivity. It is important not to exceed this, for the temperature drop between inside and outside of the arch governs the thickness that is hotter than the softening temperature.

Since the margin of safety in a furnace roof with a 15-ft. span is low, it is necessary to avoid extraneous stresses that might be set up during heating or construction, or by tightening up too much on the tie-rods. These factors have been taken into account in the construction shown in our design, Fig. 4. The roof is confined in a rather complicated steel corset, which prevents localized buckling or deformation, since it is so important that the curvature remain uniform. A 3-in. channel is placed on each rib. Five 6-in. channels, running in the longitudinal direction, rest on these smaller channels. Set bolts passing through a curved girder bear against these five channels and thus prevent any local upheaval of the arch. When the roof is new, a play of about ¾ in. is left between the set bolts and the channels while heating, but as soon as the roof has expanded, the screws are tightened.

The frame of the furnace is rigid and the horizontal thrust of the arch is opposed by set bolts fitted with springs. (See the detail in Fig. 5.) The length of these springs can be calibrated by previous tests to different values of thrust, and should be screwed up to correspond to the theoretically desirable pressure.

The projecting ribs of the arch reinforce the strength of the roof since they are at least partially air-cooled. Doubly vaulted roofs are commonly used — that is, the brick between the ribs are laid so as to form an actual arch at right angles to the arch of the rib, or are cut to form jack arches with smooth bottom lines.

The arch brick are separated by 0.030-in. sheet to form a joint.

In the arch shown in Fig. 4, the compression has been calculated at 3350 lb. per ft. of length. The maximum load that can be supported by the springs is 26,500 lb.

Roofs constructed as described above, for a 45-ton furnace lined entirely with basic refractory brick, have lasted 1100 to 1200 heats.

Roofs With Long Span

To build a roof with 20-ft. span (corresponding to a 165-ton openhearth), the height of the arch could conceivably be increased even further to avoid excessive compressive stresses. Such a solution is hardly practical, however, and would necessitate lowering the skewback to an impossible level. While some attempts along these lines have been successful in European practice, they have not been consistently so. It must be concluded, therefore, that long spans will require other methods for reducing the stresses imposed on the arch brick. For example, Reinartz, speak-

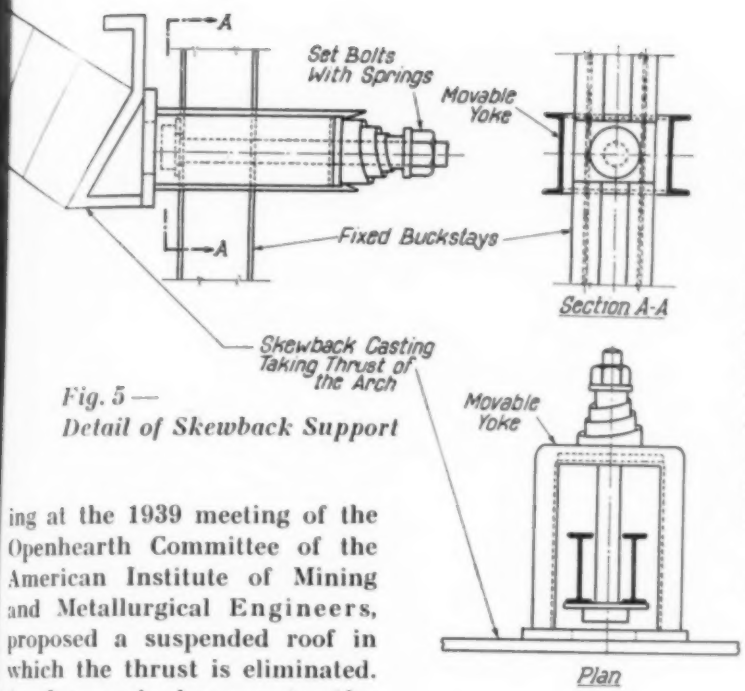


Fig. 5 — Detail of Skewback Support

ing at the 1939 meeting of the Openhearth Committee of the American Institute of Mining and Metallurgical Engineers, proposed a suspended roof in which the thrust is eliminated. As far as is known to the writer, this scheme has not yet been tried in any steel plant in Europe.

Rather, a method of "semisuspension", sketched in Fig. 6, was used just before the war. In the writer's opinion, this is better than the completely-suspended roof because it preserves intimate contact between the bricks, both in their longitudinal and in their transverse joints (the bricks being laid as a "ring arch" — that is, with no breaking of joints).

The sketch is self-explanatory. Each rib brick is pierced, and metal sleeves of various diameters used to give good alignment and equal bearing on the pin thrust through. Each suspender is adjustable by a turnbuckle. The compressive stresses in the roof are regulated as in the self-supporting roof (Fig. 4) by set bolts fitted with springs. These springs are regulated so that the thrust is about two thirds that of the self-supporting roof, although the thrust can be made much lighter provided the turnbuckles and overhead beams can support the larger part of the roof's weight. It is necessary that the load on each turnbuckle be uniform, which can be done with a spring-operated ratchet.

The author knows of only one roof for an 85-ton openhearth constructed according to this sketch. This furnace roof has attained a life of 1100 heats.

The development of this type of construction has been hindered by the war, principally by the shortage of good basic refractory brick. It also requires a large proportion of special shapes. Nevertheless, it appears to be the solution to the problem of basic roofs of long spans.

Results Obtained With Basic Linings

In general it is impossible to offset the additional first cost of chrome-magnesia refractory brick in an all-basic furnace by savings in repairs (brick and wages).

One cannot quote average figures for the life of a basic lining, because the operating conditions are too variable from one openhearth to another. A better gage would be related to the hourly production. Obviously, if increased hourly production is the chief object and is attained by greater heat input, then nothing more than ordinary furnace life can be expected of improved refractories.

The choice between increased steel production or increased lining life depends upon the savings that can be made at each individual plant. Production is the important thing in small furnaces, but it should be remembered that more tonnage is obtained only by increased heat input, which means that fuel and air must be drawn in and the products of combustion drawn off in larger quantities.

The refractory manufacturers claim that basic brick is justified (even without any increase in lining life) for any increase in production above 33% over that obtained with silica brick. This figure holds, of course, only for a given set of economic conditions. Each mill should work out its own economic balance with the actual cost of brick in place, and its own hourly refining cost.

In practice, an increase in both production and furnace life can be obtained by the use of chrome-magnesia refractory and brick. The figures quoted below are based on furnaces with ports constructed according to Fig. 3. They apply to a 50-ton furnace heated with producer gas which was run for four years with ports made of "Radex E".

Operating conditions before rebuilding with basic refractory were as follows: Port life (silica brick), 300 heats; daily steel ingot production, 185 tons; consumption of fuel in the producers per ton of steel, 2.2 tons.

After rebuilding ports with basic refractory brick these figures were: Burner life, 900 heats; daily ingot production, 215 tons; consumption of fuel in the producers per ton of steel, 2.0 tons.

To effect these results it was necessary to install fans at the gas producers and enlarge the gas mains. The annual consumption of chrome-magnesia brick was 110 tons per furnace, but 275 tons of silica brick were saved.

These results can be considered quite worth-

while in all respects. In other French steel works results have been less notable, either because the masonry was not well laid, or because the ports were not cleaned out regularly, or because production was hampered by too much low grade scrap. In one mill the roofs of basic ports settled rapidly, due to too large a span (1 m. or 3 ft. 3 in.). The stresses in the brick were too high.

Mention should also be made of one Hungarian openhearth with 35-ton oil-fired furnaces, lined entirely with basic brick. Hourly production was 9.5 tons, with an average lining life of 530 heats. Such a high production would require a 75-ton furnace if it were lined with silica brick. Such remarkable results are exceptional.

In certain openhearths specializing in alloy steels, the prime purpose in changing to all-basic construction is neither increased production nor

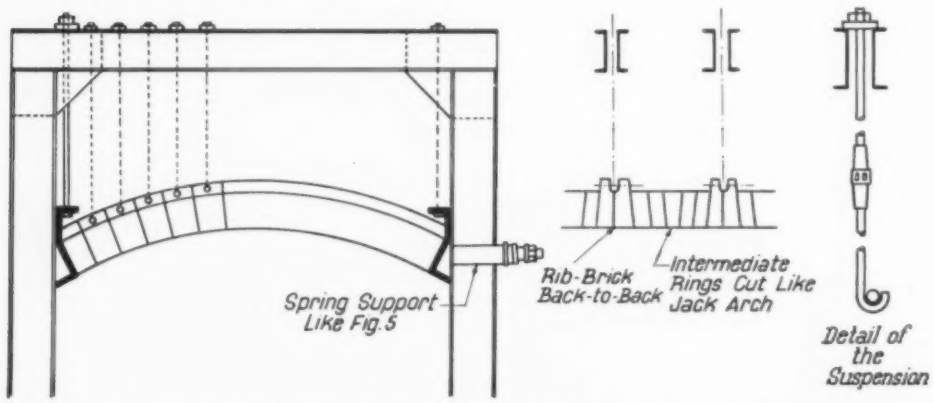


Fig. 6 — Sketch of Semisuspended Roof of Basic Brick on a 85-Ton Furnace Having a Life of 1100 Heats

increased furnace life, but to maintain the necessary high temperatures without damage to the roof. It is thus possible to maintain a quiet bath in the furnace and to alloy the steel under a deoxidizing slag comparable to those in a basic electric furnace. Further, these linings permit a more limey slag, and improve desulphurization.

In this case the advantage of basic refractory brick is harder to compute. The refining cycle being longer, the gain in hourly production is less important. In a Continental steel plant of this type, roof lives of 1100 and 1200 heats have been obtained; the fuel ports were repaired twice during each campaign. The production was increased 12% over that obtained under silica brick arches. This is an illustration of how, if higher alloying temperatures are looked for, little improvement can be expected along other lines.

Before closing it would be well to note the probable cause of some failures in basic roofs.

There is a tendency for both technical men and melters to place too much confidence in basic brick. They know that the brick will not melt, no matter what temperature the flame may have. Therefore, if the flame takes a bad direction and licks the roof, no one is alarmed, since "the brick will stand 2000° C." Little care is taken to smooth out the fuel port floors, or scrape out the rubble, and this gives the flame a poor direction until finally conditions become quite aggravated.

The writer believes that contact between gas and roof is dangerous, because the gas is reducing. The chrome-magnesia brick frequently contains as much as 10% Fe_2O_3, and when some of this is reduced it leads to the disintegration of the brick. Without doubt, it is because the fuel licks the roof in preference to the walls that it is there the basic lining begins to fail. We believe, therefore, that it is well to suspect this chemical action of the flame, and to require as good a direction for the flame with a basic roof as with a silica roof.

Conclusion

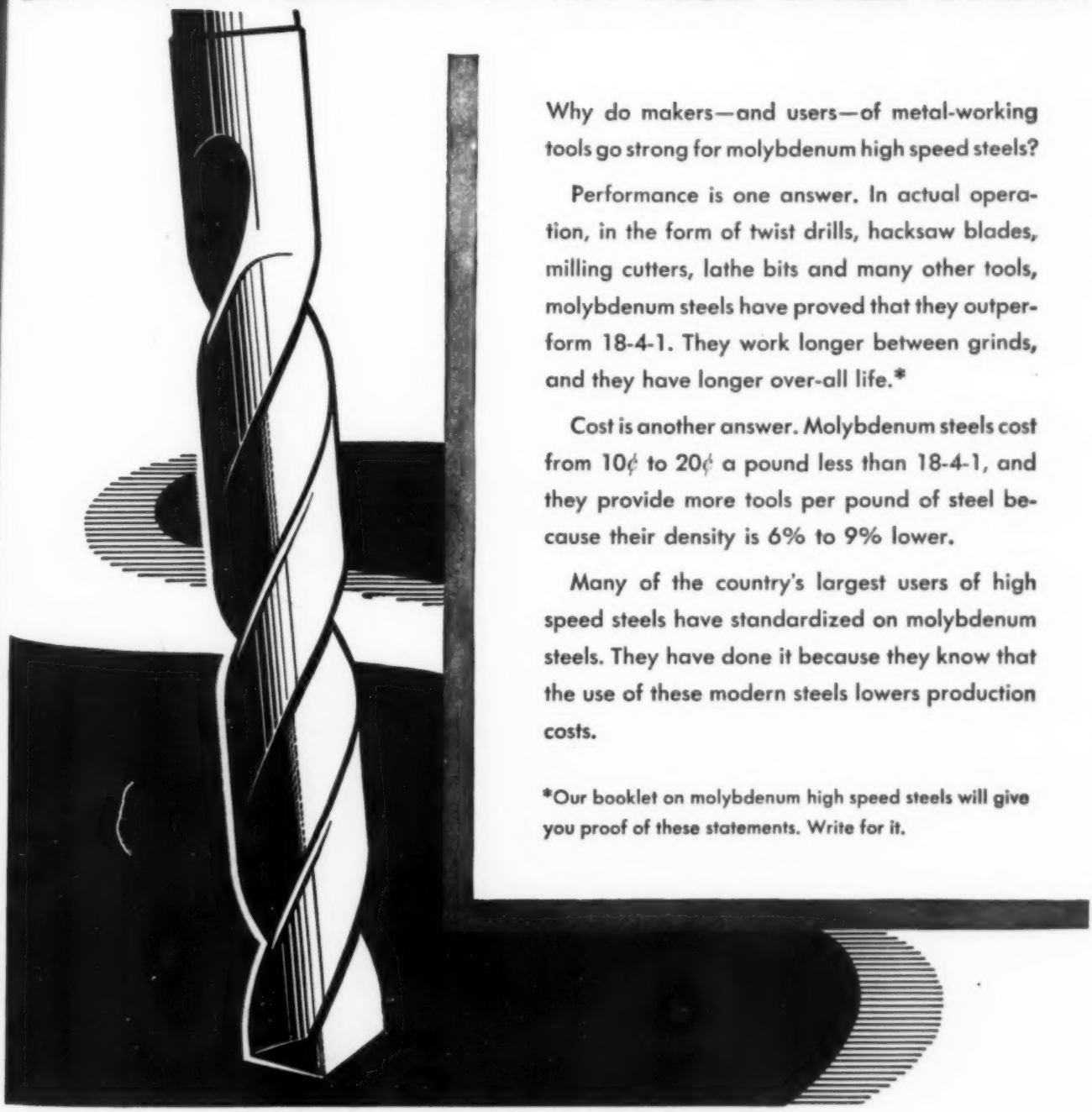
It has been shown in this paper how the use of basic refractory brick in openhearth furnaces has brought about production increases in Continental furnaces while reducing fuel consumption and increasing the life of furnace linings.

There seems to be no reason why, with complete basic lining and roof, openhearth furnaces would not produce the same tonnage with a smaller number of furnaces. In these furnaces, which are so much larger than the majority of European openhearths, it would be necessary to adopt semisuspended roofs.

The interest aroused recently by the potentialities of oxygen in a fuel-oil burner will direct more and more attention to furnace roofs and linings. If all the advantages of oxygen are to be realized, there must be an increase in use of the basic roof and port brick.

Finally, the writer would like to underscore a point that has had considerable influence in the development of the use of basic refractory brick in France and Germany — namely, the smart business policy adopted by the brick manufacturers of Central Europe. They have not hesitated to give guaranties on furnace life, which have allowed steel producers to undertake the first trials with a minimum risk.

WHY THE TREND IS TO Mo HIGH SPEED STEELS



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Personals

Carl B. Friberg, formerly forgesmith at the Cape Ann Anchor & Forge Co., is now operator of a jobbing blacksmith shop in Gloucester, Mass., which is named Industrial Blacksmithing.

B. F. Kubilius has been appointed general manager of Industrial Furnaces and Supply Co., Pawtucket, R. I.

J. K. Rummel has accepted the position of chemical engineer with Sheppard T. Powell, Baltimore, Md., consultant. He was previously chemical engineer of Shanghai Power Co., Shanghai, China.

P. Vincent Schneider, formerly with P. R. Mallory & Co., Inc., has joined the Powdered Metal Products Corp., Franklin Park, Ill., as research metallurgist.

Charles D. Townsend is now chief industrial engineer with A. B. Chance Co., Centralia, Mo.

C. James Paris, having graduated from the University of Notre Dame, is now employed as a designer in the pilotless aircraft group at Chance Vought Aircraft division of United Aircraft Corp., Stratford, Conn.

Russell F. Marande has taken the position of foundry manager of North & Judd Mfg. Co., New Britain, Conn.

David H. Gurinsky has joined the metallurgical section at the Brookhaven National Laboratory, Long Island, New York, having resigned his post at the Institute for the Study of Metals of the University of Chicago.

Lawrence M. Prescott is now associated with the Cleveland office of Philip W. Frieder division of the Luria Steel and Trading Corp. as a sales representative, after leaving the physical metallurgy division of the Naval Research Lab., Washington, D. C.

W. T. Snyder, formerly chief metallurgist, Eversharp, Inc., is now chief engineer of Herff-Jones Co., Indianapolis, Ind.

David J. Herveat, formerly chief chemist for the Solar Aircraft Co., Des Moines, Iowa, has recently accepted a position as research chemist for the International Harvester Co., Chicago, Ill., in the manufacturing research division.

After receiving his M. S. from Colorado School of Mines, **Walter C. Keil** accepted a position with Federated Metals Co. and is now located at their Newark, N. J., plant where he is working on white metals.

George J. Miller has taken a position in the industrial engineering department, Geneva Steel Co., Geneva, Utah.

J. H. Westbrook, formerly of Rensselaer Polytechnic Institute, has been awarded a research fellowship at Massachusetts Institute of Technology where he will continue his metallurgical studies.

Gerald R. Van Duzee, formerly associate professor in the college of engineering of Wayne University, has accepted a position as head of the department of metallurgy at South Dakota School of Mines and Technology, Rapid City, S. D.

After receiving his B. S. from Wayne University this June, **Edward Meier** has been employed by American Cyanamid Co. and is taking part in sales engineer training program.

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RUST PROOFING AND PAINT BONDING
Granodine *
Duridine *
Alodine *
Lithoform *
Thermoil-Granodine *

RUST REMOVING AND PREVENTING
Deoxidine *
Peroline *

PICKLING ACID INHIBITORS
Rodine *

* ®

AMERICAN CHEMICAL PAINT CO.
AMBLER ACP PENNA.

Let Trouble be our Introduction

THERE'S nothing like trouble to bring people together. That's how some of Revere's closest friends were gained—through a mutual struggle against difficulties, troubles such as occasionally beset any business.

Take the case of an important product, originally developed for war uses, now finding many applications in peacetime services. When manufacture began, rejections ran extremely high, over 40%, costs were skyrocketing, and badly-needed production was being lost. The maker asked if we would care to collaborate in solving the problem. Of course we would! After studying the subject in detail (and also under conditions of the greatest secrecy), we suggested a radical change in the properties of a non-ferrous metal used in the manufacture of the vital part with which so much trouble was being experienced. New processes of manufacture were developed, and in a short time test runs of the recommended material proved successful. Rejections of finished units dropped to less than 1%. Thus an expensive and vexing bottleneck was broken, and we gained a new customer and a firm friend.

This success story demonstrates that Revere has an open mind as well as an informed one, and is always ready to question the customary, find new answers to new problems, or to old ones, for that matter. If something is worrying you in your employment of non-ferrous metals, get in touch with Revere, not for ready-made answers, but for wholehearted cooperation, a joint search for better results. This help is given freely, without obligation, through the Revere Technical Advisory Service, which has at its command the knowledge and facilities of our laboratories, and the accumulated experience of the entire Revere organization.

REVERE

COPPER AND BRASS INCORPORATED

Founded by Paul Revere in 1801

230 Park Avenue, New York 17, New York

Mills: Baltimore, Md.; Chicago, Ill.; Detroit, Mich.; New Bedford, Mass.; Rome, N. Y.—Sales Offices in Principal Cities, Distributors Everywhere.

Personals

Melvin D. Coughenour has been appointed by Carpenter Steel Co. as their sales representative in the Syracuse territory.

Fred Kisslinger, at present at the Institute for the Study of Metals, University of Chicago, will start as a member of the department of metallurgical engineering at Illinois Institute of Technology in September.

E. E. Hussey, formerly sales engineer of Globe Hoist Co., Philadelphia, is now head of the engineering department in the industrial division of the same company.

Egor Paul Popov is assistant professor of civil engineering at the University of California, Berkeley.

Resigning his position with the Chicago, Rock Island & Pacific R.R., **Cecil A. Christian** has accepted a post teaching heat treating and metallurgy at the vocational school in West Allis, Wis.

John J. Daly, Jr., formerly with the U. S. Navy, is now metallurgical engineer at the Hawthorne Station plant, Chicago, Ill., of Western Electric Co., Inc.

Amadeo Sangenis is in this country getting practical experience in iron and steel at the Gadsden, Ala., plant of Republic Steel Corp., after which he will return to Mexico to utilize his experience.

George B. Waterhouse, past president of the American Society for Metals, is at present in Bogota, Colombia, where, at the request of the Colombian government, he will investigate the facilities for establishing a steel plant.

E. O. Ek, president of Ek and Co., New York City, is representative in this country of Wikmans-Hytte Steel Works, Sweden.

Bradley F. Bennett has been transferred from assistant repair superintendent at Naval Shipyard, Pearl Harbor, to engineering services officer, Naval Research Laboratory, Bellevue, D. C.

Robert B. Wallace, a former secretary-treasurer of the Mahoning Valley Chapter and metallurgist for Carnegie-Illinois Steel Corp.'s Youngstown district, has been transferred to the alloy unit, metallurgical division, Carnegie-Illinois, Pittsburgh.

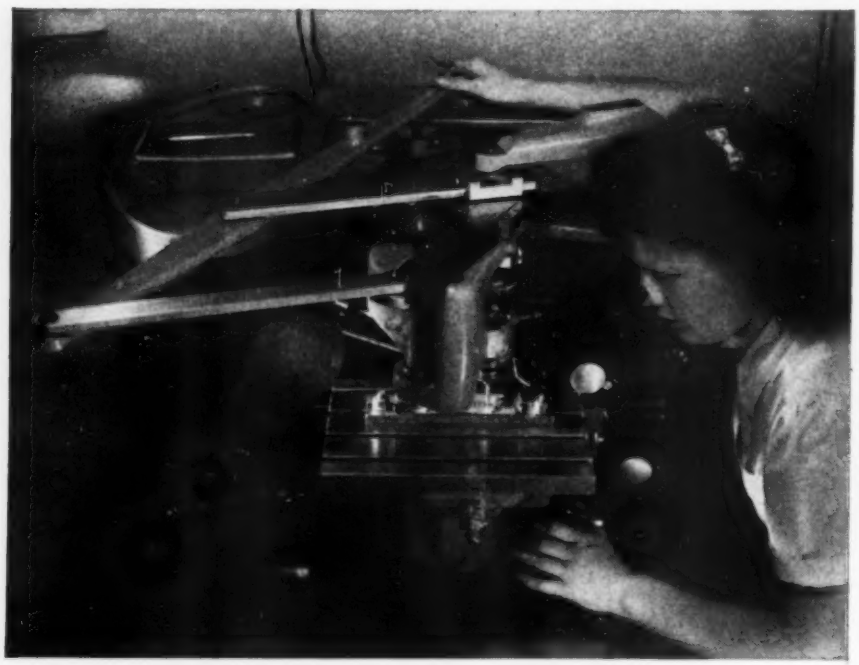
John D. Shoffner, formerly at Colorado Fuel & Iron Corp., is now enrolled at Colorado School of Mines.

Resigning from the sales department of the Detroit office of Carpenter Steel Co., **John C. Brackett, Jr.**, has become a partner in the John Brackett Co., New York City, district representatives of Joslyn Stainless Steels.

On the opening of offices in Portland, Ore., and Seattle, Wash., by A. F. Holden Co., **Burt Payne, Jr.**, has been put in charge of West Coast sales.

John M. Blalock, Jr., has resigned his position with Battelle Memorial Institute and is now connected with General Chemical Co., Chicago, as a technical service representative in their Baker and Adamson division.

G. F. Cady, Jr., formerly with Chicago Bridge & Iron Co., has formed the Cady Metal Engineering Co., North Tonawanda, N. Y., in conjunction with his father and brother. The new company will specialize in welded fabrication of steel, stainless steel, aluminum and other alloys



She SEES it better
she MAKES it better

This operator *knows* that her work will pass inspection. With the aid of a Spencer *Stereoscopic* Shop Microscope she sees smaller details and controls her operation more accurately. The result is less scrap; lowered costs; increased profits.

Designed to meet critical wartime requirements, the Spencer Shop Microscope offers manufacturers new possibilities for quality control at every point—inspection of raw materials, toolmaking, tool inspection during operation, fine machining, and final inspection. Equipped with or without standard base, it is adaptable and can be permanently mounted to your equipment. Choice of optics offers magnifications from 9X to 54X.

For further information write Dept. W119.

- ★ INJECTION JET DRILLING
- ★ WATCH ESCAPEMENTS
- ★ FINE ENGRAVING
- ★ PRECISION GRINDING
- ★ HAND BROACHING
- ★ SMALL PARTS INSPECTION
- ★ LENS MOUNTING
- ★ DIE SINKING
- ★ MANY OTHER TOOL-MAKING, FABRICATING, AND INSPECTION PROBLEMS

American Optical
COMPANY
Scientific Instrument Division
Buffalo 15, New York

Manufacturers of the SPENCER *Scientific Instruments*

ALWAYS LOOKING INTO THE FUTURE

Injecting oxygen into the molten steel bath

another Airco first

Today, steel making in the Open Hearth stands on the threshold of far reaching developments thanks to the cooperation of leading steel mills with Airco research.

The basis of this research is Airco's development of a practical method of injecting oxygen directly into the molten steel bath through the slag cover.

This opens up new avenues of approach in controlling, and in materially reducing the refining period.

Yes, tomorrow's steel will be produced faster due to this important use for oxygen . . . as developed by Airco technicians.

This promising new technique, which is exciting the imagination of steel makers, is another outstanding example of Airco's continuing effort to provide time-saving, product-improving tools and processes for ALL industry. The facilities of our Technical Sales Division are available to you in applying Airco techniques and products to the solution of your problem.

If you desire further information about this process, please direct your request for a copy of our bulletin, "Use of Oxygen In The Open-Hearth Bath", to Dept. 5650, Air Reduction, 60 East 42nd St., New York 17, N. Y. In Texas: Magnolia Airco Gas Products Company, Houston 1, Texas.

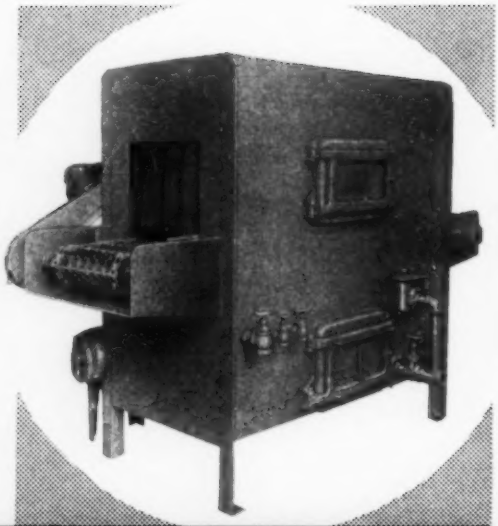
AIRCO **AIR REDUCTION**

Offices in All Principal Cities

Originators of Modern Oxyacetylene Flame and Electric Arc Methods For ALL Industry

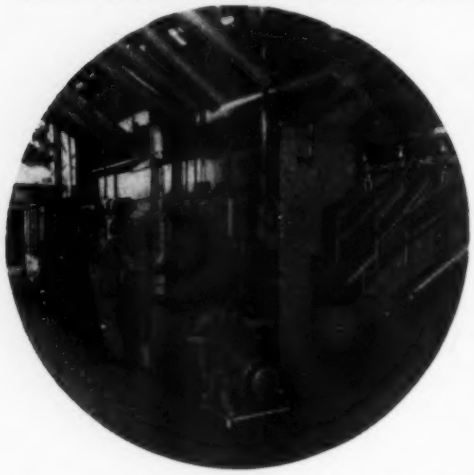
Quality-Controlled Products

Cleaned Efficiently, Economically!



WHY BE SATISFIED WITH LESS?

If you have the problem of cleaning metal products of various sizes and shapes, you may find this small, compact and inexpensive A-F Product Washing Machine that can be placed directly into a conveyorized production line — or used as a separate machine — the answer to your problem. There are *specialized* metal parts and products cleaning jobs, however, that require especially designed and engineered machines. In these cases, remember that A-F Engineers specialize in custom-built equipment to do a specific cleaning job.



AT LEFT: Part of an Alvey-Ferguson Completely Coordinated Conveying and Cleaning System for metal containers.

Metal Show
CHICAGO
Oct. 18-24
VISIT OUR
BOOTH No. 1037

Completely synchronized and conveyorized cleaning systems, engineered by Alvey-Ferguson, are reducing production costs for many prominent manufacturers.

If you have a problem of this type, why not write today for folder describing how others clean their metal products with A-F "standard" and "custom-built" equipment!

THE ALVEY-FERGUSON COMPANY
164 Disney Street Established 1901 Cincinnati 9, Ohio
Offices in Principal Cities Coast-to-Coast

CONVEYING EQUIPMENT
Alvey-Ferguson
METAL PRODUCTS CLEANING EQUIPMENT

Personals

Edwin F. Cone has retired from his editorial work on *Materials and Methods*. He became editor of its predecessor, *Metals and Alloys*, in 1935 after having spent about 20 years on the editorial staff of *Iron Age*. His specialty (if metallurgical editors can have such luxuries) was the steel foundry industry. He also had a penchant for collecting statistics on new branches of metallurgical production, in several instances carrying on for years before the respective trade associations recognized the infant industry's importance. E.E.T.

Dick Jansing, formerly metallurgist at Inland Mfg. Div., General Motors Corp., is now design engineer with Hudson Sharp Machine Co., Green Bay, Wis.

Julius Heuschkel has recently been placed in charge of welding research activities at the Westinghouse Research Lab., East Pittsburgh, Pa.

Jack Goudzwaard, a recent graduate of Michigan College of Mining and Technology, is now taking a management apprentice course at Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

After receiving his M. S. from Carnegie Institute of Technology in May 1947, **Alfred Goldberg** accepted the position of research metallurgical engineer at the University of California at Berkeley.

Reginald C. Fisk is now research and development metallurgist with the Neveroil Bearing Co., Wakefield, Mass.

Formerly with the Office of the Inspector of Naval Material, **R. J. Fulvi** has joined the industrial engineering department of Capewell Mfg. Co., Hartford, Conn.

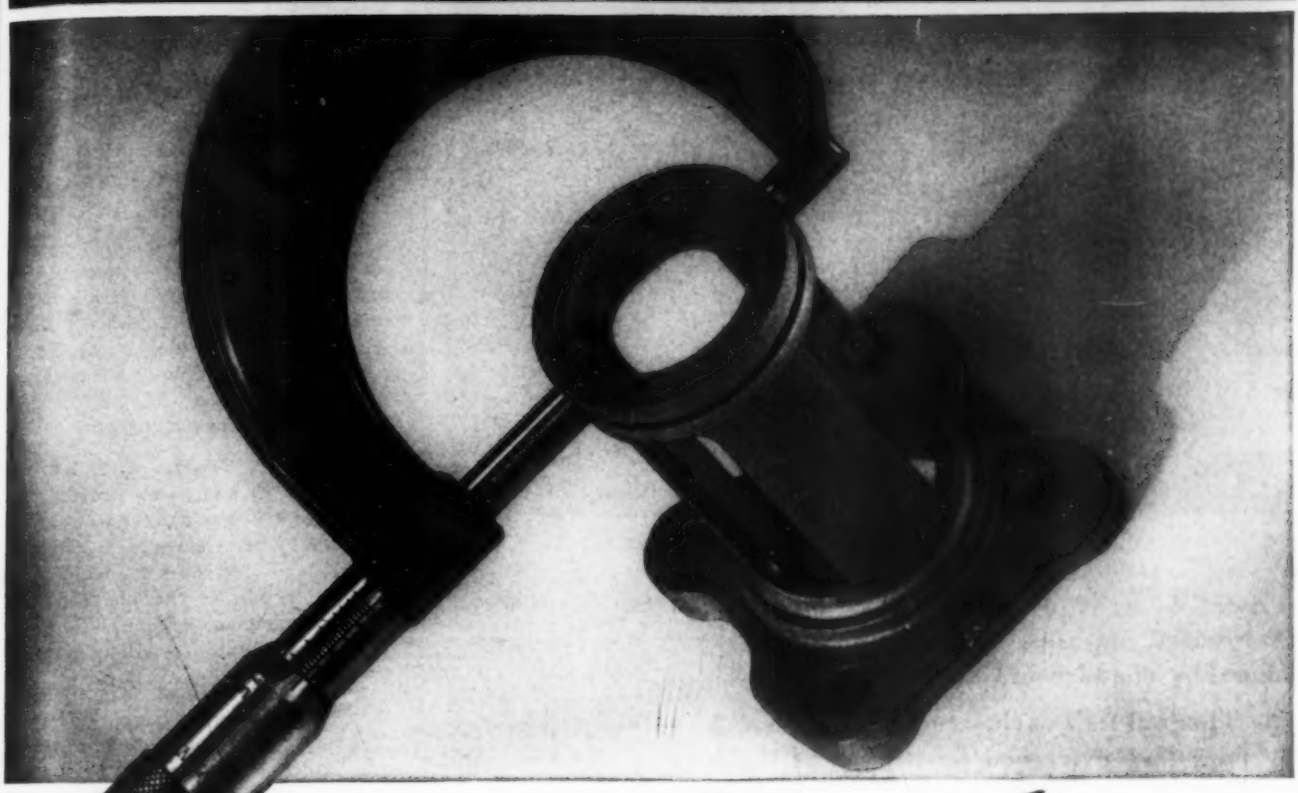
Completing graduate work at the University of Cincinnati in June, **Marvin L. Steinbuch** has joined the research and development department of the Lunkenheimer Co., Cincinnati.

Wm. H. Wilson is now a junior metallurgist for methods of testing at Monsanto Chemical Co.'s Clinton Laboratories, Oak Ridge, Tenn.

Resigning his position as senior metallurgist in the development section, materials laboratory, Wright Aeronautical Corp., **James H. Keeler** has become a research assistant in the department of metallurgy, Pennsylvania State College.

MISCO *Precision* CASTINGS

CAST TO MICROMETER TOLERANCES



84% *waste material eliminated*

You Need This Booklet

It contains the latest precision-casting information available

Our new 20 page booklet completely describing the Misco Precision Casting Process is ready for you. Profusely illustrated, and in full color, this booklet is invaluable to engineers, metallurgists, production and purchasing executives in those industries requiring small, accurate parts in large quantities. We shall be glad to forward your copy.

The metering valve illustrated above is part of an aircraft carburetor and weighs 7¾ ounces as cast. It was formerly machined from a stainless steel bar weighing three pounds. There is a saving of 84% in weight of expensive material and a more considerable saving in machining time. The Misco Precision Casting held to tolerances of ±.003" per linear inch needs only minor finishing operations.

Misco Precision Castings are available in high strength hardenable steels as well as Austenitic stainless types such as 18-8. The range offers maximum resistance to heat, corrosion and wear. Quantity production can be scheduled for quick delivery with extremely low tooling cost. Let our engineering department assist with your design, production and material problems.

PRECISION CASTING DIVISION

Michigan Steel Casting Company

MISCO
Heat and Corrosion Resistant Alloys

One of the World's Pioneer Producers of Heat and Corrosion Resisting Alloys

1999 GUOIN STREET • DETROIT 7, MICHIGAN

New Lincoln "Fleet-Arc" Simplifies AC Welding

Building a machine base with the "Fleet-Arc" AC Welder.

A NEW heavy duty transformer type welder, the "Fleet-Arc," which improves and simplifies AC welding, has been introduced by The Lincoln Electric Company.

This welder's exclusive "Arc Booster" greatly simplifies arc striking and gives good penetration at the start of the bead. The instant the electrode touches the work, the arc strikes automatically and digs in deeply because of the extra burst of current supplied by the "Arc Booster." In a fraction of a second the current returns to the amount set for the job.

ARC STRIKING AUTOMATIC

With arc striking made automatic by the "Arc Booster," the operator can get started easily and quickly—increasing production speed. There are six degrees of booster current, to suit all types of work.

Current adjustment of the "Fleet-Arc" is step-less, smooth and accurate. The operator simply turns a hand wheel. Amperage is shown on a calibrated dial. A double-reduction chain drive minimizes turning. Rugged cone brakes prevent vibration and wear of the control mechanism.

This welder is completely safe because its open circuit voltage never exceeds 63 to 70 volts (depending on welder capacity). Its design reduces the amount of condensers required as much as 66%, minimizing idle current input—an important economy feature, since in most shops a welder idles at least 60% of the time.

The above is published by LINCOLN ELECTRIC in the interests of progress. Complete information on the "Fleet-Arc" AC Welder is given in Bulletin 366. Write The Lincoln Electric Company, Dept. 233, Cleveland 1, Ohio

Personals

Jessop Steel Co., Washington, Pa., announces that **Richard M. Paxton, Jr.**, has been elected vice-president of the company. Mr. Paxton has been with Jessop Steel since 1924 and for the past 20 years has been manager of the New York branch office.

Alan Goldblatt, consultant for the Applied Research Laboratories, has opened a spectrochemical testing and consulting service, Chicago Spectro Service Lab., Inc.

Howard L. Edsall, formerly with the Radio Corp. of America, has accepted the position of director of public relations of Eutectic Welding Alloys Corp., New York. Mr. Edsall, a member of the Advisory Committee of *Metal Progress*, has just written two books (nonmetallurgical).

Donald E. Thomas and **Robert L. Hadley** have been awarded fellowships for postgraduate study in metallurgy at Carnegie Institute of Technology, Pittsburgh. Mr. Thomas is studying under the sponsorship of the International Nickel Co. and Mr. Hadley of Titanium Alloys Mfg. Co.

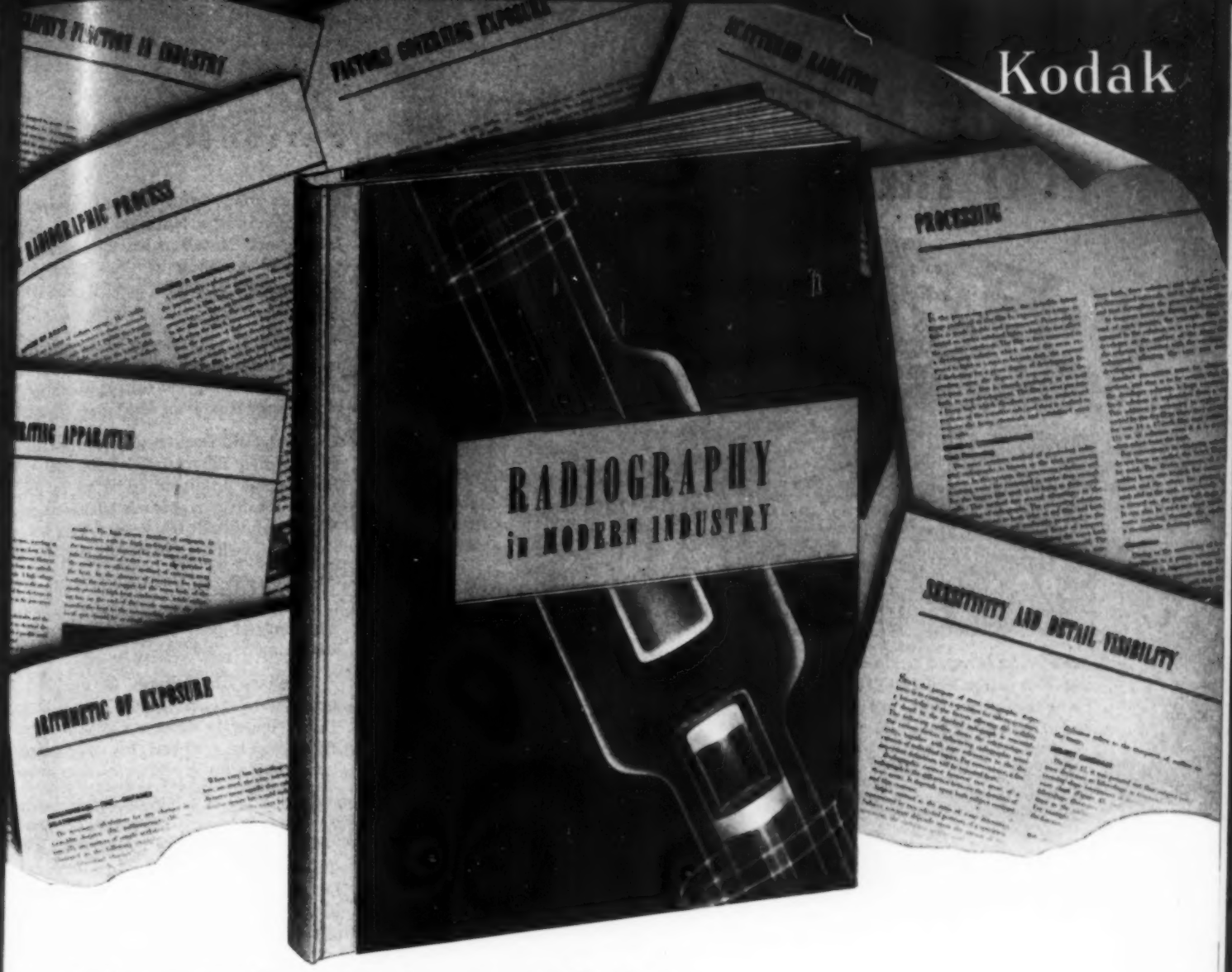
Formerly engineer and designer for Ford Machinery Corp., **William T. Tiffin** is now associate professor of mechanical engineering at the University of Florida, Gainesville, Fla., where he will teach courses in metallurgy and metallography and assist in a course in manufacturing methods and operations.

Permanente Metals Corp. announces that **T. W. F. Foster** will be sales engineer of their newly formed aluminum pig and ingot sales division.

Carpenter Steel Corp. announces the promotion of **Berton H. DeLong**, formerly vice-president and chief metallurgist, to the position of vice-president and technical director. At the same time, **George B. Luerssen**, formerly assistant chief metallurgist, was promoted to the post of chief metallurgist.

W. S. Rockwell Co., Fairfield, Conn., announces the appointment of **D. A. Gilbert**, formerly with Chase Brass and Copper Co., Cleveland, as their exclusive agent for the state of Ohio.

Wm. J. Miller is working in the chemical department of the Pittsfield, Mass., works of the General Electric Corp., under the advanced scientific training program.



Designers, engineers, foundrymen, metallurgists, quality-control men, radiographers, welders . . .

. . . here's a *NEW* book that will answer your questions about x-ray practice and technics . . . clearly, quickly, authoritatively. Price $3. Order your copy now.

BETWEEN the covers of this book is a complete, authoritative x-ray text . . . an invaluable answer book on practical x-ray questions. It gives industrial x-ray users the most up-to-date . . . the most clear-cut operating data available!

Every important phase of radiography is thoroughly discussed in its 122 pages. Data are completely backed up . . . by 64 highly illustrative photographs . . . 38 colorful drawings . . . 44 newly published, clearly presented tables and charts!

This material gives you the answers to questions like these: *How can I get higher contrast and better detail visibility in my radiographs? . . . Can I improve sensitivity by processing longer? . . . Can I increase penetration with intensifying screens? . . . Is agitation during development important?*

Here is your guide to more efficient x-ray results. Order your copy of "Radiography In Modern Industry" from your local x-ray dealer.

EASTMAN KODAK COMPANY
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Radiography . . . another important function of photography

Here is the Capacity You Need to HEAT TREAT SMALL PARTS...

EFFICIENTLY

Save Power, Time and Space with this NEW, Complete Line of

COOLEY ELECTRIC BOX FURNACES

Save large furnace equipment for the big jobs . . . use COOLEY Electric Furnaces for accurate and economical heat treating of *small parts.*

When you have a COOLEY, there is no need to wait for large furnace time or use the power required to heat such a furnace. Always-ready COOLEY Furnaces give you convenient capacity for small work, together with highly accurate temperature control, simplicity of operation, unusual flexibility and an operating cost as low as 4¢ per hour. These efficient box furnaces are now available in 11 types and sizes to offer the correct model for your requirements *(see table below).*

2 TYPES OF AUTOMATIC CONTROL

For hardening and other *high temperature work* to 1850° F., MH and VH model furnaces are for use with indicating and controlling pyrometers, mounted separately or as part of a factory wired panel and stand integral with the furnace.

For precision control of heating from 300° to 2000° F., including *low temperature applications* such as tempering or drawing of steels, non-ferrous heat treating, etc., MK and VK model furnaces are equipped with a Selective Power Modifier to supplement the controlling pyrometer. This combination corrects the characteristic lag of chamber temperatures behind the pyrometer reading to as low as 300° F., and eliminates low temperature overshooting.

USE COOLEY FURNACES FOR:

- **Metallurgical Laboratory Heat Treating.**
- **Tool and Die Heat Treating.**
- **Pilot Runs to Establish Procedures and Scheduling.**
- **Production Heat Treating of Small Parts — Normalizing, Annealing, Hardening and Drawing.**
- **Hot Forming Steel; Enameling; Glass Annealing.**
- **Emergency Repairs and Maintenance.**

CHAMBER	8"W 6"H 14"L				10"W 6"H 18"L				8"W 6"H 14"L
MAX. TEMP.	1850° F.				1850° F.				2000° F.
AMPERES	14.8 at 230 v.				19.6 at 230 v.				20.2 at 230 v.
WATTS	3400				4500				4650
MODEL*	MH-3	VH-3	MK-3	VK-3	MH-4	VH-4	MK-4	VK-4	VK-5
PRICE	146.00	166.00	186.00	206.00	222.50	242.50	262.50	282.50	340.00

* M models complete with hinged door and hearth plate.
V models have counterweighted vertical lift door with adjustable opening.
K models include Selective Power Modifier for input control to correct temperature lag.

FORCED CIRCULATION AIR DRAW FURNACES — Write for data.

ACCESSORY EQUIPMENT

Electronic operated Veri-Tron indicating and controlling pyrometer, with thermocouple and lead wire $143.00
Same in self-contained, enclosed panel including line switch and fuses, with steel stand—completely wired 240.00
Steel stand with shelf 35.00

DEALERS AND DISTRIBUTORS WANTED!
Good territories open on this extensive line of self-contained small electric furnaces. Investigate now.

FREE LITERATURE

NEW CATALOG completely describes all models and applications for each. Write today for your copy . . . no obligation.

COOLEY ELECTRIC MANUFACTURING CORP.
50 South Shelby Street Indianapolis 7, Indiana
INDIANAPOLIS MACHINERY EXPORT CORP.
Export Manager, 44 Whitehall Street, New York, New York

Personals

Chun-Ping Ming, a research assistant in the National Bureau of Mining and Metallurgical Research of China, is studying at Case Institute of Technology under a special scholarship.

James W. Martin is now sales engineer for Schmitt Steel Co., Portland, Ore., doing consulting work for them and others on the West Coast.

R. Condit Becker recently left the welding laboratory of Rensselaer Polytechnic Institute to work in the manufacturing research department of International Harvester Co., Chicago, as welding research engineer.

Wayne H. Glover, formerly on the staff of Purdue University, is now metallurgist at Indiana Gear Works, Indianapolis, Ind.

Leonard J. Schmid has been transferred from A. C. Spark Plug Div., General Motors Corp., to the Allison Div., where he is bearing metallurgist.

Col. Welton J. Crook, professor of metallurgy, School of Mineral Sciences, Stanford University, and **Ralph Neuhaus**, vice-president and general manager of Hughes Tool Co., Houston, Tex., were among those who recently received special recognition of wartime activities by Army Ordnance Assoc.

Donald A. Hilliard, formerly with Landers, Frary & Clark, New Britain, Conn., is now technical director of the Clinton Co., Chicago.

Formerly supervisor of the metallographic unit of the Curtiss-Wright Propeller Div., materials laboratory, **William C. Coons** is now metallographer of the research unit of the Johns Hopkins University's applied physics laboratory, Silver Spring, Md.

Emil Dubeck, who has been plant superintendent and works manager of the Warren Tool Corp. for the past 16 years, has assumed control of the H. J. Harrold Tool Co., Columbiana, Ohio.

Having received his M. S. from Michigan College of Mining and Technology in June, **Edward T. Kubilins** has been appointed metallurgist for the Saginaw Malleable Iron Co., Saginaw, Mich.

Marvin E. Leonard is now general foreman of heat treatment at Nylen Products Co., Saint Joseph, Mich.

raveling, we encounter many unique and interesting
rupations, such as carving rosettes on merry-go-round
rses, pre-priming the Bull for entering the Bull Ring,
d Pin-head Engraving. While visiting an animal hos-
al we encountered another unique craftsman, Adolph
kelberger, who shaves tummies on dogs and tabbies
eparatory to abdominal operations. He uses a straight
or. "I tried an electric shaver but it tickles too much,"
d Adolph. "My bowel-barbering is a specialized art."
keep fleas off the target he uses a mixture of wood
cohol and fine sand. "The wood alcohol drives them
zy and they stone each other to death with the sand,"
plains Adolph.

DO YOU USE PUSHER FURNACES?

you use the conventional Pusher-Tray furnaces, you
ve observed a great difference in pushing THRUST
quired between different furnaces. You have probably
ticed how the thrust pressure required to operate the
rnace continually increases with time of use, often
coming three to five times the initial thrust. This is caused
A, increasing bearing friction; B, the sagging workage
d angulation of the rails with a resultant cam or "wash-
ard" deformation which causes the trays to move up
d down and sideways against each other *when under*
usts measured in tons. Great energy must be trans-
itted through the trays acting as a ram.

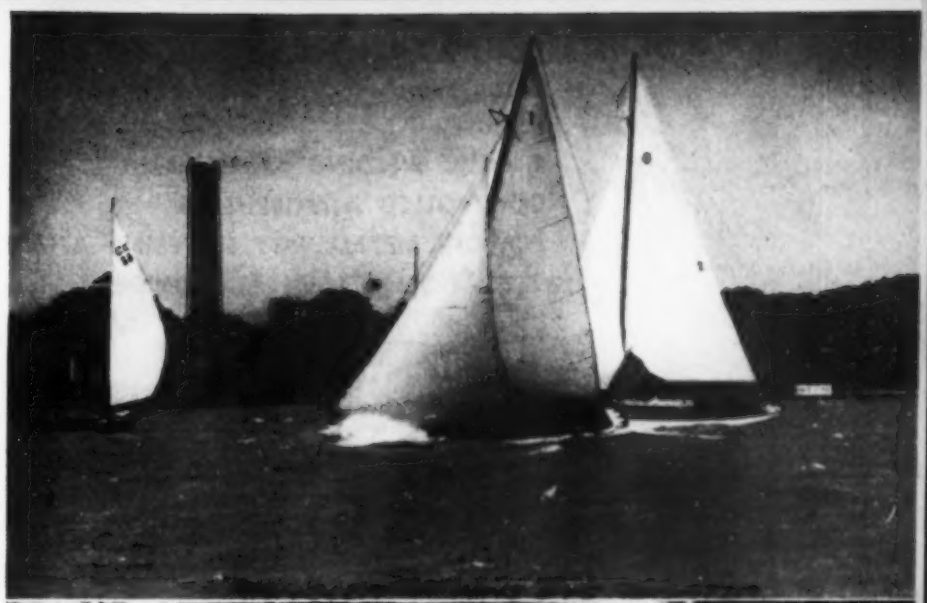
Much of this rail friction and irregularity results from
ils being *bought on price to low standards.* Such "cheap"
ils are generally made with high scrap content, having
gher bearing adhesion; bearings and rollers are com-
only crude fits.

ll rails warp in casting, due to the differentials in
rinkage stresses during metal solidification and the re-
rictions to natural shrinkage by gates, cores, etc. Usual
undry practice is to straighten such warped rails with
sledge or press, resulting in a "straight" cold rail which
mpily warps to relieve these stresses when heated. (GA
s specially developed foundry technique to correct this
ndition.) Obviously, trays must be made much heavier
d stronger so that they will still live after the rails
arp and the thrust increases.

eneral Alloys, of course, has rail designs which greatly
duce rate of frictional increase and deformation. Such
ils make possible the use of materially lighter trays.
he extra cost of G.A. "MUFFLE-RAILS" is about
% on the rails. This added first cost is only about 5%
the saving resulting from increased tray life. Furnaces
e often bought strictly on price, causing the furnace
ilder to buy the cheapest castings from cheap patterns.
ecause of this initial "economy" on rails having a total
lue of $1,500 to $2,000 on a $30,000 furnace using six
fifteen thousand dollars worth of trays, the user has
spend more for heavier trays to start with and ulti-
ately pays-through-the-nose by buying 50% to 100%
ore trays than would be necessary if the furnace "road-
d" was a high class General Alloys rail installation.

n the light of modern engineering, pusher furnaces have
en obsolete for several years. You consider that a tray
rnace with no end-thrust on trays, which can be run
ntinuous-flow, intermittent-flow or reversed, and which
n run one tray at a time or a full load, is an engineering
dvance. Further, you may consider that having to push
dummy load into a furnace and heat it, in order to get
e "pay-load" out when shutting the furnace down, and
en re-heating a dummy load and shoving it through a
ll cycle in order to start up the furnace, is a wasteful
rocedure.

he General Alloys "*Smooth-Screw*" *Furnace Conveyor*
atented), installed in 1939 and still going strong, elimi-
ates all the disadvantages of the pusher-tray furnace,
tains all its advantages and has many exclusive features
d economies. *It will pay for itself in tray life alone.*
ost pusher furnaces are "white elephants" when opera-
ns are slow. They are costly to shut down and cannot
e operated without well-loaded trays. "Smooth-Screw"
nveyors can be supplied to any furnace builder for
stallation in a new furnace or can be installed as re-
acements in most pusher-type furnaces.



Andy Langhammer, undoubtedly the best ballast on any sail boat, is still gathering laurels as a Racing Skipper. His 38-foot sloop Rambler VI easily won the Detroit Yacht Club Regatta, defeating the new Mackinac Class and such fine boats as the Blitzen, three New York 32's, and others. Sailing with Captain Langhammer was a picked crew of Detroiters and J. C. Colquhoun of the Deben Yacht Club, Woodbridge, Suffolk, England. As president of Chrysler Amplex Division, Andy Langhammer makes many outstanding products including "Oilite" bearings and super-fine powder metallurgy parts from gears to gauges.

"Equipoise" muffles (H.H.H. patent) equipped with reinforcing full-form circumferential corrugations have unique advantages: (A) They cannot collapse; (B) They permit free heat circulation around the entire muffle; and (C) They slide easily on supporting rails.

Most important, they have far longer life than any similar muffles made. From the small one shown, to gas carburizing muffles 40 feet long and special forms up to 5 feet wide, 4 feet high and 53 feet in length, "Equipoise" muffles are available in a variety of sizes. Some of these muffles have run more than 50,000 hours in gas carburizing and are still going strong. They cost 20% more than the cheapest stuff you can buy and run 200% longer.

P.S. This is an advertisement of GENERAL ALLOYS COMPANY, "oldest and largest exclusive manufacturers of heat and corrosion resistant castings." Home office — Boston, U.S.A. — offices in principal cities.

for
NITRIDING STEELS
BRIGHT ANNEALING
ATOMIC WELDING AND BRAZING
CONTROLLED ATMOSPHERES
POWDER METALLURGY SINTERING ATMOSPHERE
REDUCTION OF METALLIC OXIDES

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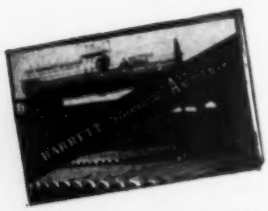

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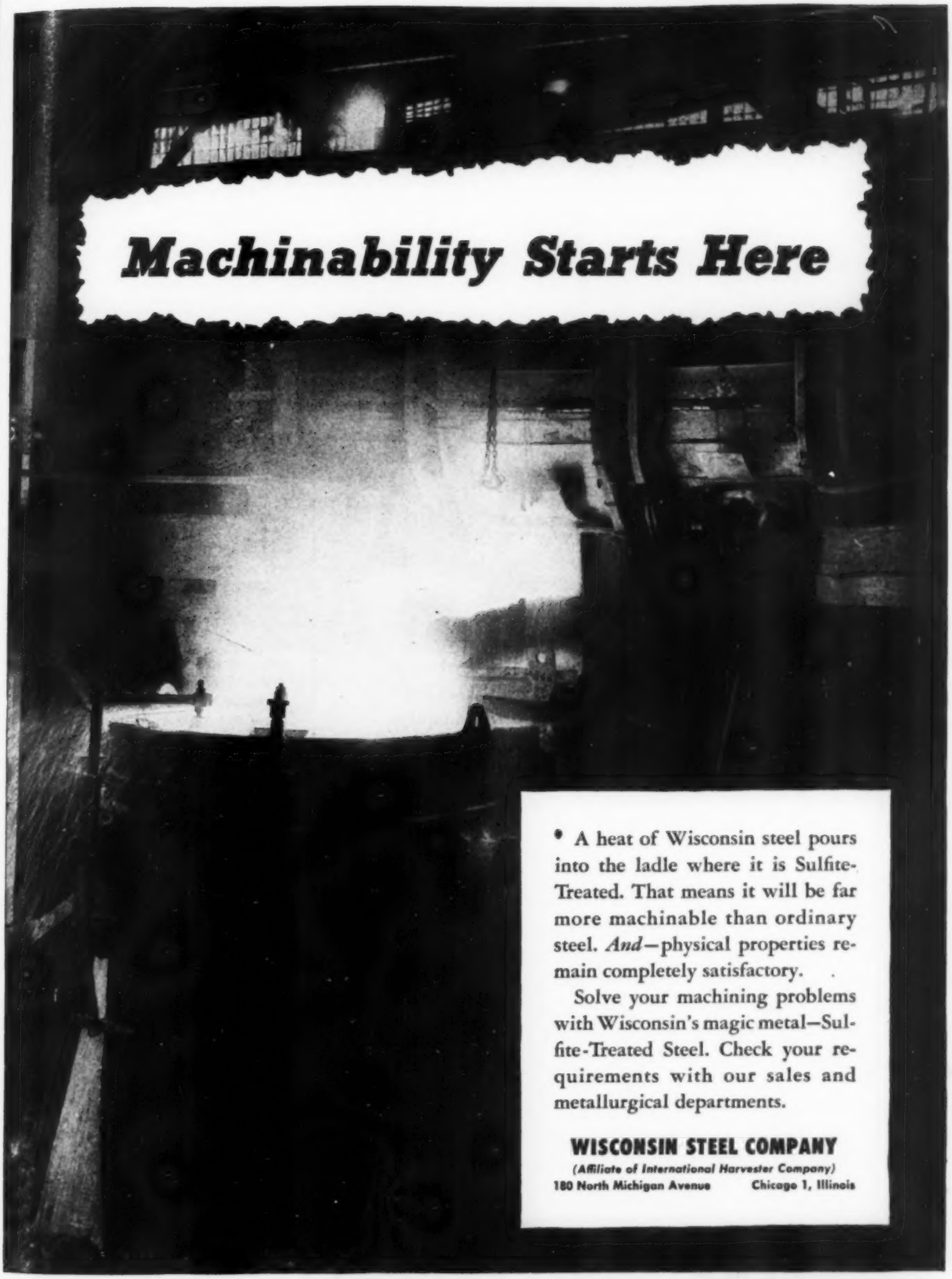
Aging Theory*

TENSILE and resistivity tests were used to follow the room-temperature age hardening of four different high-purity alloys of the duralumin type, on the basis that rejection of solute atoms from a supersaturated solid solution must be preceded by an incipient stage wherein solute atoms move into interstitial lattice spaces. There is a definite relationship between the elastic limit and the specific electrical resistivity on the one hand and the rate of egress of solute atoms on the other.

Interpretation of the test results leads to a new theory of age hardening. The egress of solute atoms creates vacant sites in the lattice. Concentration of the vacant lattice sites during room-temperature aging follows an exponential function, the elastic limit increasing with the cube root of the concentration of vacant lattice sites while the electrical resistivity increases directly in proportion to this concentration itself. It is thought that a vacant lattice site must have qualitatively the same effect on resistivity as a stranger atom in solid solution. If that be true, the resistivity must increase in proportion to the rate of egress of solute atoms in room-temperature aging; this is in good agreement with the experimental results. Likewise, the crystal lattice is broken up by the vacant sites into slip elements just as in cold work it is broken up into mosaic elements. Thus, work and age hardening can now be ascribed to the same fundamental mechanism. Distribution of sites appears to be pseudo-regular.

Further tests were carried out on the aging of these alloys at 320° F. directly after quenching and after initial aging at room temperature. Two difficulties were encountered in trying to explain the results on the basis of the above theory. In direct aging at temperature, the initial resistivity increase is far too brief as compared with the increase in strength. Secondly, with additional aging, the decrease in strength can be accounted for but there is no explanation for any subsequent increase. Consequently, the theory of the mechanism of vacant lattice sites was modified. *(Cont. on p. 424)*

*Abstracted from "A Theory of the Age-Hardening of Aluminum-Copper Alloys, Based on Vacant Lattice Sites" by F. Röhner, *Journal* of the Institute of Metals, V. 73, Part 5, 1946-1947, p. 285 to 321.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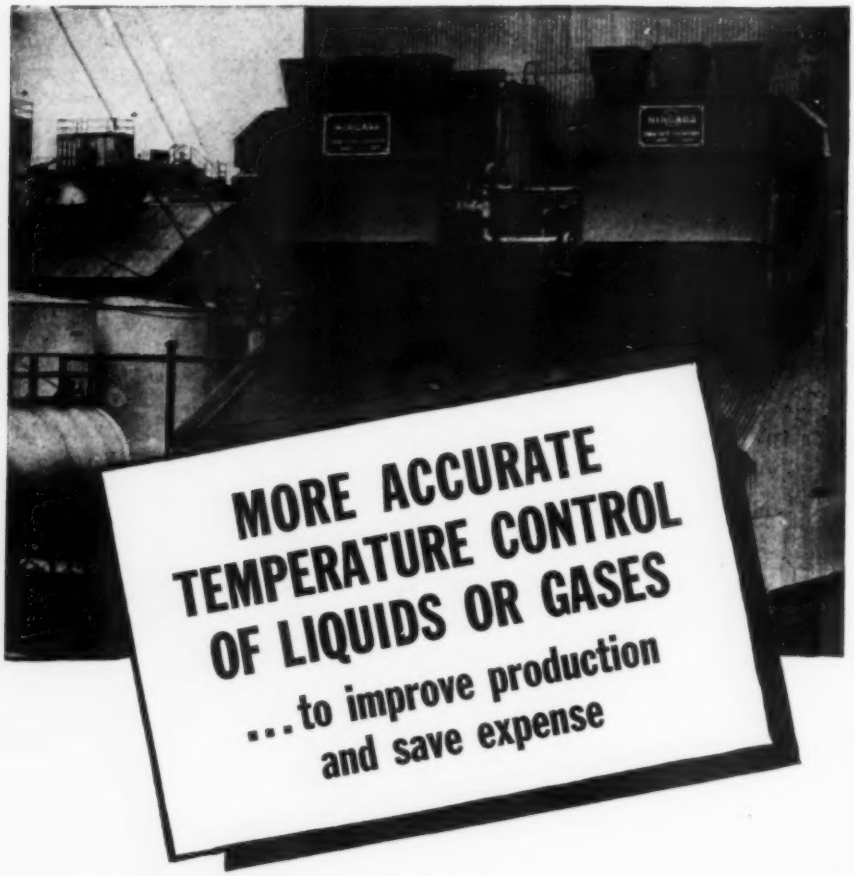

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Aging Theory

(Continued from page 422)

Vacant sites are filled by self-diffusion of the solvent metal, which action has a decisive influence at elevated temperatures. Even larger vacant regions may be formed which are more difficult to fill. Strength will generally be increased by vacant regions, just as it is by vacant sites, but the effect of vacant regions on electrical resistivity will be incomparably smaller than the effect of vacant sites. Restoration effects are explained by the fact that the proportion between the sites and the regions is dependent on the temperature.

Vacant lattice sites, as a mechanism of aging, are explained by the electron theory of metals. A supersaturated solution tends to reject its solute ions, and the rejection involves an electrical discharge. A requisite step to such a discharge is the dissociation of the solute ion from its lattice place, resulting in an ion in the interstitial lattice space and a vacant lattice site. Both these dissociation products, the negative vacant site and the positive ion, are capable of diffusion, the rate of diffusion of the site being determined by the rate of self-diffusion of the solvent metal. Further, the dissociation products can both be discharged — that is, rejected — from the lattice. Discharge of a vacant site results in the transformation to a vacant region if it is taking place within a grain; if it is taking place at a boundary (a filling-up process) the result is a minute extension of the boundary.

Vacant regions are electrically neutral; they may be looked upon as discharged and thereby stabilized sites. Electrical resistivity is reduced by both kinds of discharge, but strength properties are reduced to a considerable extent only by the latter kind. The discharge of solute ions can take place at boundaries or vacant regions, and results in the formation of precipitates.

The concentration of vacant sites cannot exceed a certain amount because the negative sites and the positive ions attract each other. Under conditions unsuitable for discharge, dynamic equilibrium will soon be reached at a constant concentration of vacant sites while supersaturation is still persisting. If, however, the sites are continually discharged, as in elevated temperature aging, the whole supersaturation may eventually be relieved. *(Continued on p. 426)*

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*"*A Study of Polarized Vertical Illumination," L. V. Foster—Jrnl. Optical Society of America, 28, April, 1918, pp. 124-129*

**"*A Polarized Light Compensator for Opaque Materials," A. F. Turner, J. R. Benford, and W. J. McLean—Econ. Geology, 40, No. 1, Jan.-Feb., 1945*

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Single Inlet Wheel, showing closed end and shaft

Aging Theory

(Starts on page 422)

The chief difference between this theory and the precipitation and dispersion theories lies in the concept that the aging effects are caused by the formation of vacant lattice sites and regions which stand in a preparatory relation to precipitation. Precipitates and agglomerations are formed, but they are of secondary importance as far as strength and resistivity are concerned.

Reading Metal Temperature*

ACCURATE determination of liquid metal temperatures is essential for the control of melting operations. In general, temperature measuring instruments for foundry use must be accurate within about ± 10° at 2900° F. They must respond quickly to temperature changes, must be rugged but portable, and should have low initial and maintenance costs. The operation should be simple and the instrument both recording and direct reading.

Various methods of temperature measurement, including the spoon test, rod-cutting method, bath-equalization method, graphite-silicon carbon thermocouple, and the dissolving-tube method have their peculiar advantages and disadvantages. For investigation, the Ford Motor Co. selected two methods of considerable promise — a radiation-type pyrometer and an immersion-type thermocouple.

In the original radiation method, a steel pipe was submerged and air forced through the opening to form a bubble in the metal. Temperature readings were obtained by an optical pyrometer sighted through the tube on the inside wall of the air cavity. In the modified self-recording radiation pyrometer studied, a thermopile with a suitable optical system was mounted close to the orifice and connected with a self-recording instrument. The instrument consists of the immersion unit containing the photo-electric cell and the self-recording equipment. Air pressure plays *(Cont. on p. 428)*

*Abstracted from "Determination of Molten Metal Temperatures" by G. Vennerholm and L. C. Tate, American Foundrymen's Association *Preprint* No. 47-5 (1947).

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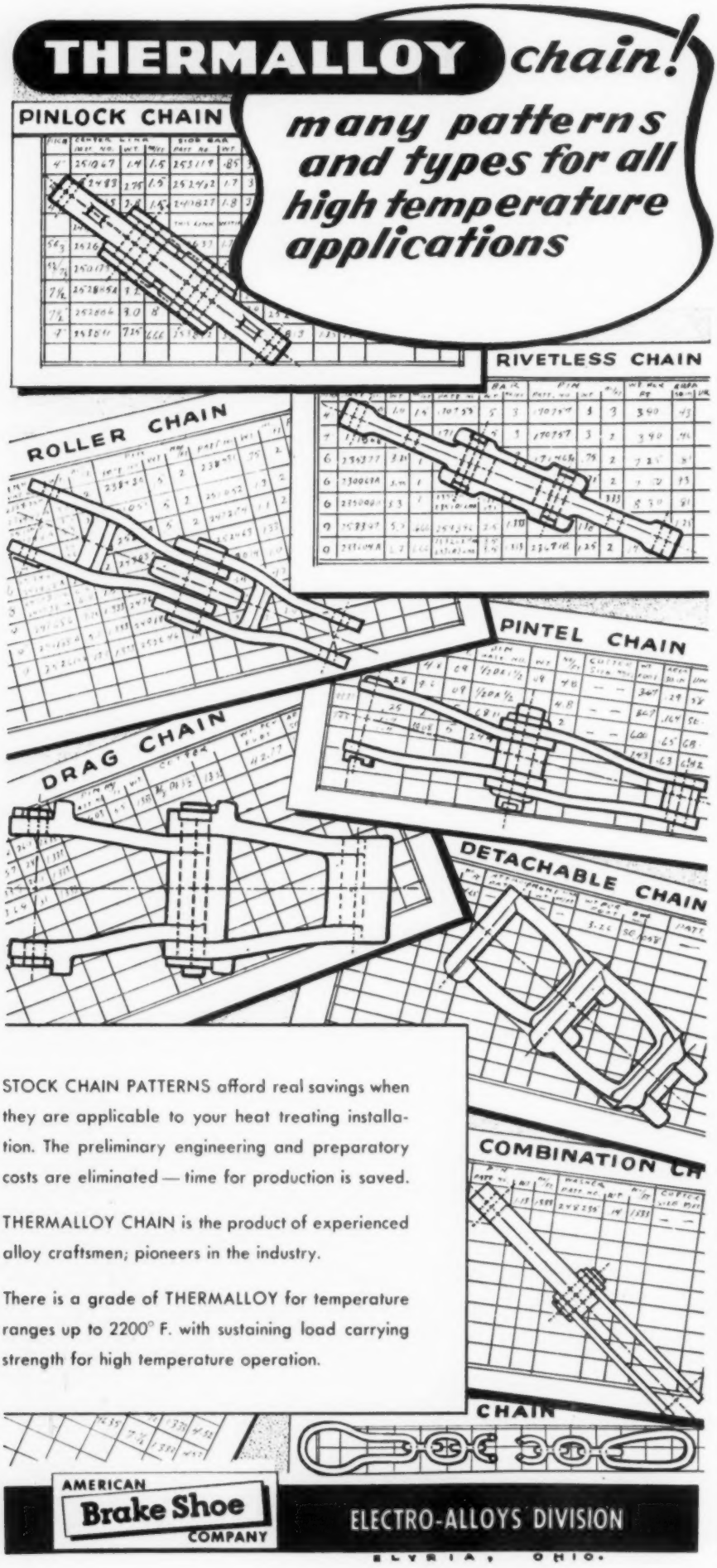
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Reading Metal Temperature

(Continued from p. 426) a vital part if consistent readings are to be obtained. Experience has indicated that best results are obtained with an air pressure of 12 psi. and an immersion of 6 in. It is advisable to standardize the instrument once a day. Reading, which requires about 12 sec., is relatively simple and can be performed by one man. Maintenance costs appear, from the present results, to be low.

The direct reading platinum immersion thermocouple consists of an extension pipe, an electronic potentiometer recorder, and an immersion head containing a fused silica tube which comes in direct contact with the molten metal and a graphite extension block which acts as a protection at the slag line. The head is preheated a few seconds, then immersed. After about 35 to 40 sec., the temperature curve levels off and the unit is removed. The silica tube should be replaced before taking a new reading, and the thermocouple, which is calibrated against a standard couple, is generally used for about ten readings. Then about ¼ in. is removed, the wire ends are rewelded and the entire couple annealed. The thermocouple is replaced after about 275 to 300 readings. The accuracy, depending upon proper care of the hot junction, is within 10 to 15° at 2900° F.

Both instruments are accurate, reliable and easy to handle. The radiation instrument is best when a complete time-temperature record is desired. It requires little maintenance and suffers a minimum of damage when adverse slag conditions are encountered. Under operating conditions, the error does not exceed about 10° at 2900° F.

When an instrument is to be used to record the ladle as well as the furnace temperature, the thermocouple is better. It requires no correction for emissivity as the actual temperature is recorded. However, the cost of replacing the silica tube each time is rather high (about $1.00 plus labor).

It is intended in the near future to investigate the radiation-type pyrometers which sight a "rayotube" into an enclosed protection tube submerged in the molten metal. These instruments are particularly interesting to foundries as they provide a complete temperature record for the entire heat.

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Embrittlement of Copper*

THE MECHANISM of the well-known embrittlement of copper by bismuth has been studied and the mechanical properties of phosphorus-deoxidized copper containing up to 0.01% bismuth were determined by notched-bar impact tests at temperatures up to 1560° F., and by notched-bar and reverse-bend tests after quenching from similar temperatures. Embrittlement was also induced in copper by the transfer of bismuth vapor to the copper.

In the tests at temperature, the effect of bismuth in causing embrittlement at 840 to 1110° F. was apparent with a content as small as 0.0005%. However, specimens tested at room temperature after quenching from this range showed embrittlement only when bismuth was 0.002% or more. It is believed that the phosphorus in the alloys, generally about 0.04%, was able to counteract the embrittling effect of smaller amounts of bismuth after quenching. (In the room temperature tests, the notched-bar impact values of the copper with 0.002% bismuth reached that of the bismuth-free copper after quenching from 1200° F.) With higher bismuth contents, the notched-bar values recovered at a temperature which increased with the bismuth content, reaching 1380° F. with 0.01% bismuth. Compared with quenched specimens of the same composition, the notched-bar values at temperature were lower in the brittle range, and the return to the properties of the bismuth-free copper usually took place at a higher temperature. Both the degree of embrittlement and the range of temperature over which brittleness exists were found to increase with the bismuth content.

Embrittlement was also influenced by the grain size of the copper, the efficiency of deoxidation of the original melt, the residual phosphorus, and the presence of bismuth vapor in the annealing furnace's atmosphere. *(Cont. on p. 434)*

*Abstracted from "The Mechanism of the Embrittlement of Deoxidized Copper by Bismuth" by E. Voce and A. P. C. Hallowes, *Journal* of the Institute of Metals, V. 73, Part 6, 1946-1947, p. 323 to 376.

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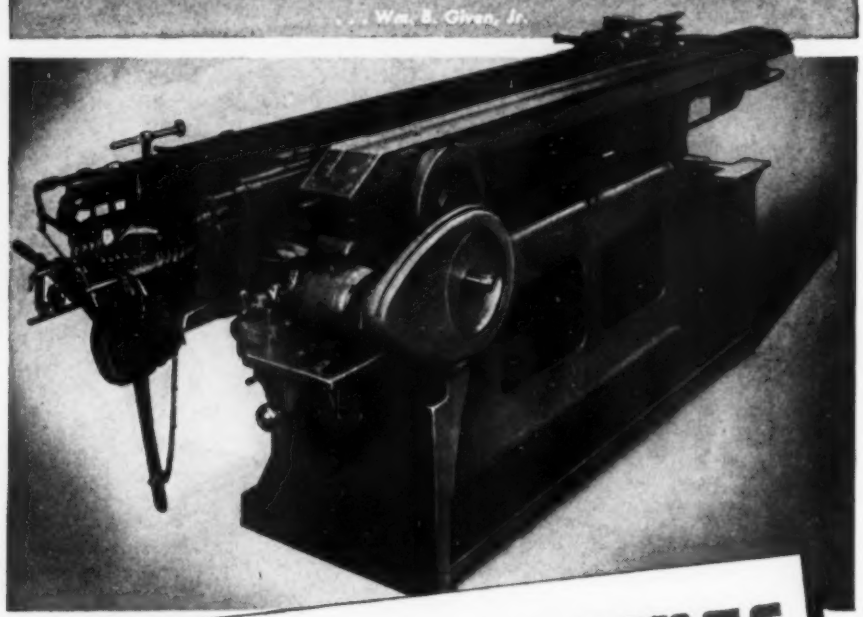

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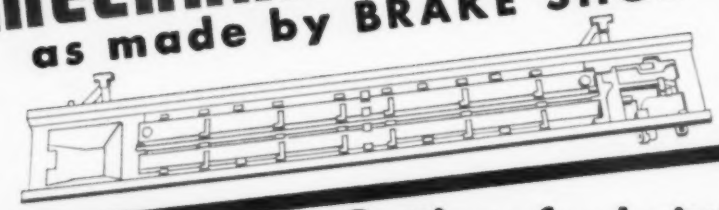
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Copper Embrittlement

(Cont. from p. 432) The larger the grain size, the less was the concentration of bismuth necessary to cause maximum embrittlement. While most of the results showed a systematic variation of properties with bismuth, some specimens were less brittle than would have been expected from the bismuth content and the grain size. One type of anomaly, noticed both at temperature and as-quenched, is believed to be caused by inefficient deoxidation which leaves some of the bismuth in a permanently oxidized condition, possibly as a phosphate. In the second type, the embrittlement at elevated temperatures was normal but the copper was tougher than expected after quenching. The relatively high P (0.04 to 0.28%) with 0.01% Bi may account for this as high phosphorus counteracts the bismuth in the as-quenched condition but not at elevated temperatures.

It is concluded tentatively that a film of elementary bismuth at the grain boundaries and not a compound of bismuth with any other element is responsible for the embrittlement. However, it is not clear why no change in toughness was detected in passing through the melting point of bismuth. It is deduced that the embrittlement is fully developed when the intercrystalline concentration of bismuth corresponds approximately to a monatomic layer covering the whole intercrystalline surface area, since an increase then has no appreciable effect on toughness. It is assumed that all the bismuth occurs at the grain boundaries at temperatures up to 1110° F. At higher temperatures, an increasing amount dissolves. Solubility of bismuth in phosphorized copper increases from less than 0.001% at 1110° F. to 0.01% at 1470° F.

The degree of permissible embrittlement will depend on the working operation to which copper is to be subjected. The bismuth content for a given degree of embrittlement depends upon the annealing or working temperature, the grain size, the presence of counteracting elements such as phosphorus and oxygen and the presence of impurities or minor constituents which may affect the solid solubility of bismuth in copper. In view of the complexity of the problem, it is understandable that close limits for allowable bismuth contents can be specified only as a result of plant trials.

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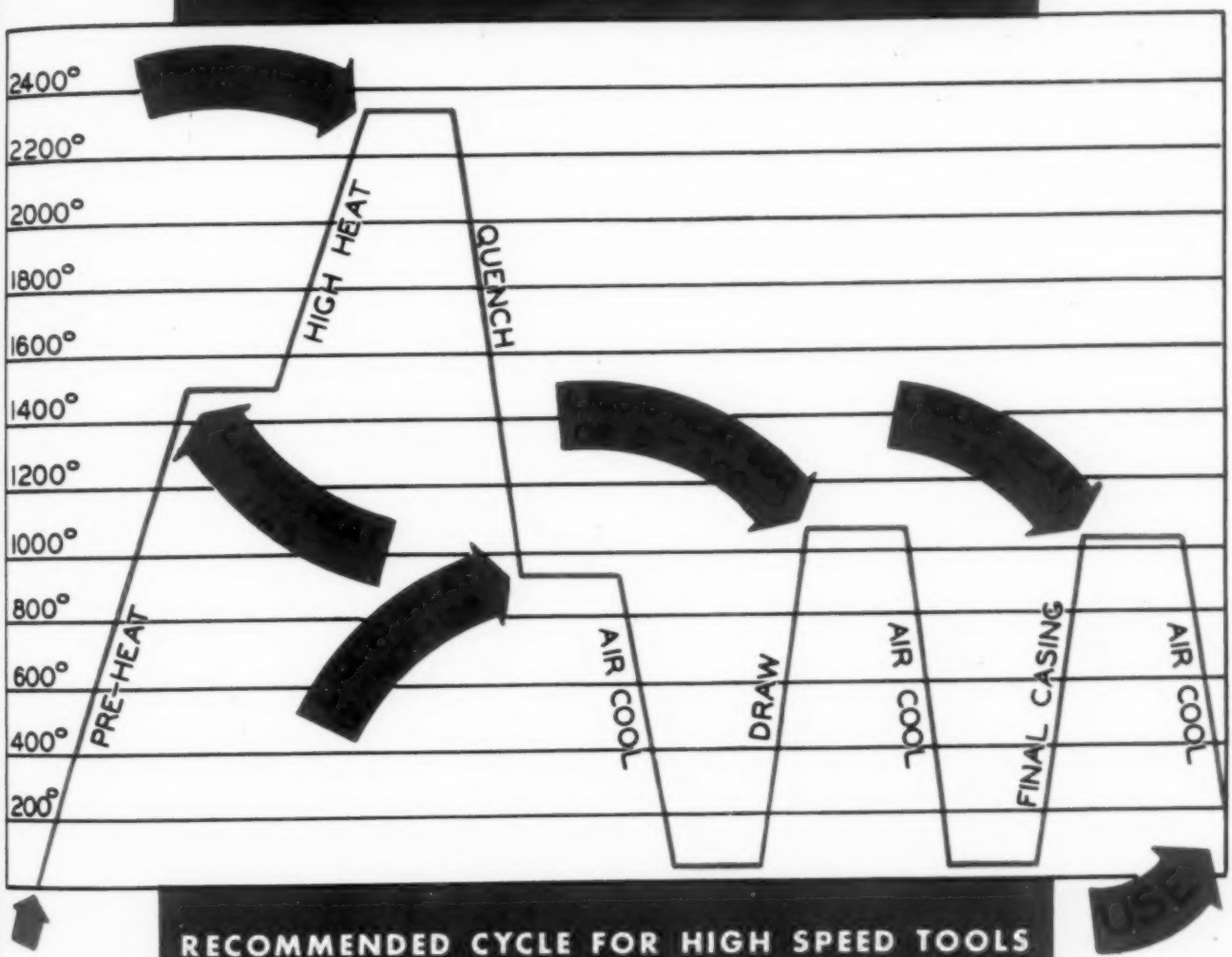

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Heat Treatment of Welds in Hard Steels*

INVESTIGATIONS on the relationship between welding and TTT or S-curves have dealt mainly with low-carbon low-alloy steels. There has been little correlation between them and the preheating temperature necessary to prevent cracking, and the postheating cycle to assure a ductile heat-affected zone for the average deep hardening steel. Nevertheless, by the proper utilization of S-curves, one can avoid excessively high preheating temperatures and ineffective postheating treatments.

(The method of determining S-curves and M_s temperatures is discussed briefly in this article and several S-curves are given. The martensite point may also be calculated from composition.)

Martensite formation is closely related to preheating practice. In preheated deep hardening steels, the rate of formation of martensite is slowed and its quantity modified, since no transformation to martensite occurs above the M_s temperature. (Fine pearlite and bainite—an acicular constituent—will form between Ar_1 and M_s.) The following rules are established for the proper preheating temperature:

1. Steels with 0.45% carbon maximum:

(a) For highly stressed welds with mild steel rod or large jobs with austenitic electrodes: 500° F. or the M_s temperature, whichever is lower.

(b) For most applications: 300° F., at which temperature about 10% martensite is formed.

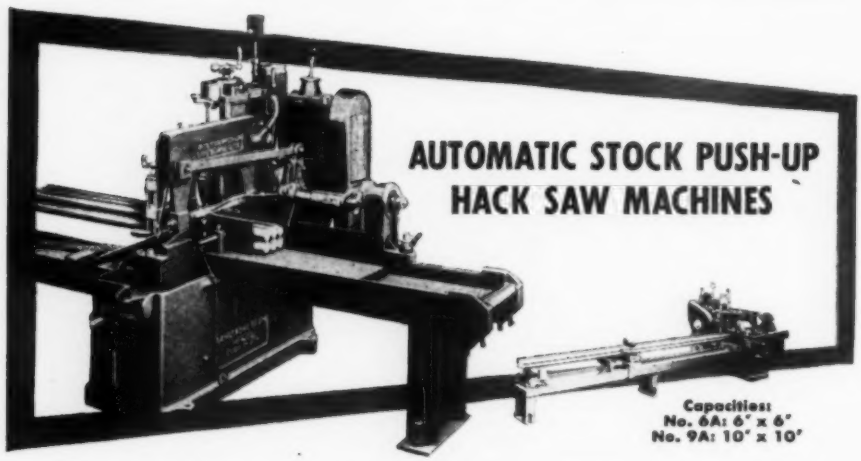
2. Steels with over 0.45% carbon:

(a) For annealed high speed steel and medium and highly stressed welds: 400° F., which is approximately the M_s temperature or above.

(b) For overlays and build-ups: 250° F. for steels over 0.70% carbon, and 350° F. for steels with 0.45 to 0.70% carbon.

(c) For hardened steels with notches near the weld: A temperature as near the tempering temperature as possible. *(Cont. on page 440)*

*Abstracted from "The Use of Direct Transformation Data in Determining Preheat and Postheat Requirements for Arc Welding Deep Hardening Steels and Weld Deposits" by L. F. Bowne, Jr., *Welding Research Supplement*, April 1946, p. 234-s to 241-s.



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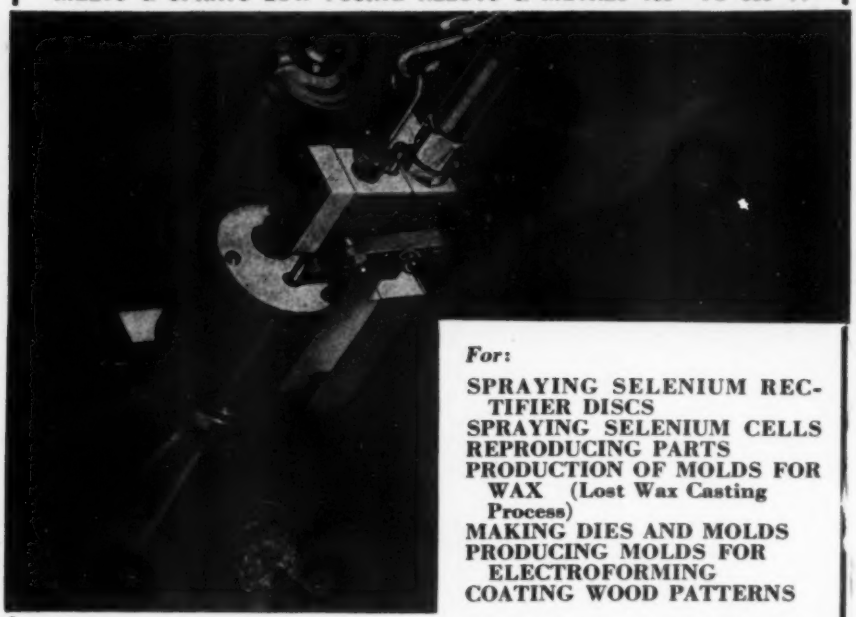

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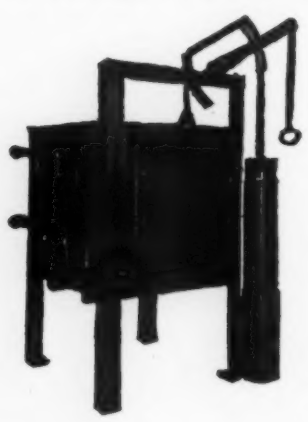

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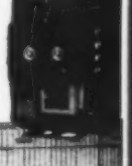

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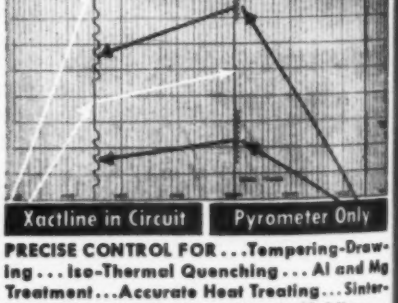

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Heat Treatment of Welds in Hard Steels

(From p. 436) (d) For unnotched hardened high speed steel: 800° F.

After being welded, steels with below 0.45% carbon are either cooled to room temperature and tempered, or put immediately into a hot furnace for direct transformation treatment. Steels containing over 0.45% carbon are charged into a furnace for direct transformation or a double temper before they cool below 125° F. Deep hardening weld deposits with 4 to 12% chromium should not be permitted to cool below 300° F. If the martensite reaction is incomplete at room temperature or at the temperature to which the weldment is permitted to cool after welding, a single temper will toughen the martensite existing at the start of the tempering operation and transform most of the retained austenite while cooling after tempering. Consequently, the heat-affected zone will have low ductility due to the untempered martensite resulting from this transformation. A double temper or direct transformation should then be used; time and temperature for the latter may be determined from the S-curve but a suitable factor of safety should be used.

Weldments containing over 6% chromium have better ductility and impact strength if they are annealed by a combination temper and transformation treatment rather than by direct transformation because chromium steels tend to precipitate a grain boundary carbide on direct transformation. This tendency becomes more pronounced as the chromium increases over 6%. The weld is cooled as low as possible before reheating in order to form a maximum of martensite, then reheated to 1350° F. to temper the martensite and permit the remainder of the austenite to transform.

Welds containing about 0.10% carbon and 15 to 18% chromium are partially ferritic. Lower preheating temperatures are used for these grades than for the 3 to 12% chromium steels since the M_s temperature of the austenitic portion is lower and the steels do not reach as high a hardness. For proper ductility, it is important to cool the higher chromium weld deposits well below the M_s temperature before postheating as the tempered martensite plus ferrite structure so formed is much more ductile than the direct transformation product plus ferrite.